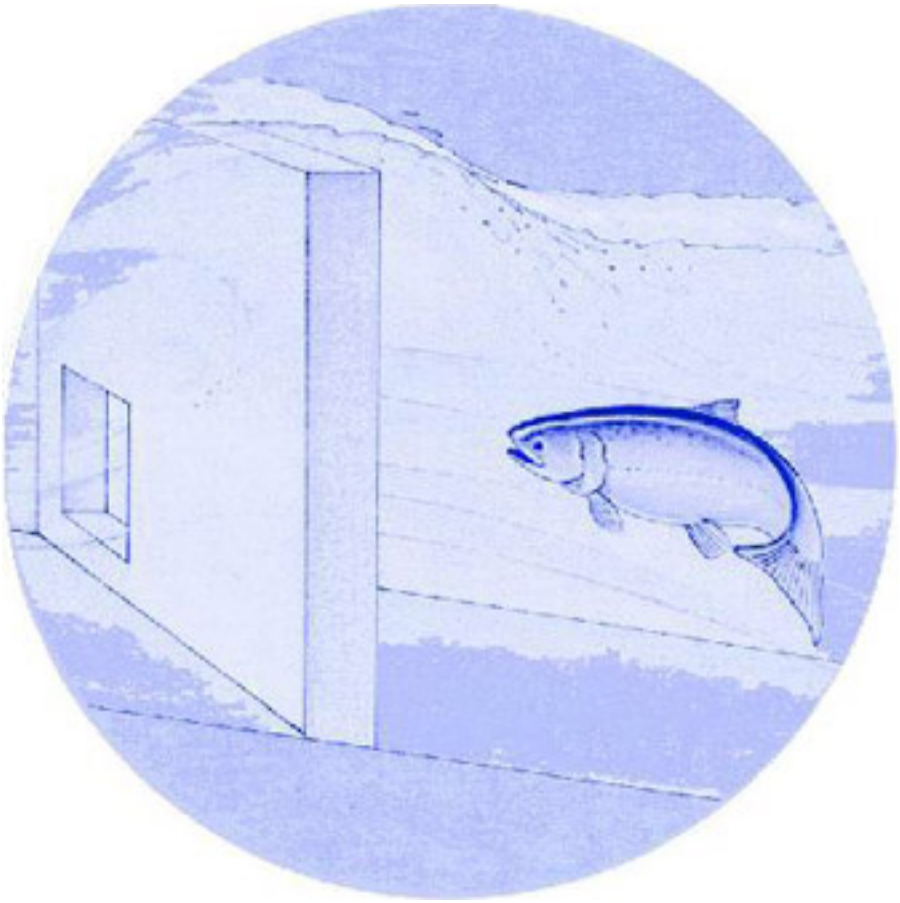
# Reproductive Ecology of Yakima River Hatchery and Wild Spring Chinook

## Yakima/Klickitat Fisheries Project Monitoring and Evaluation Report 3 of 7

**Annual Report**
**2003 - 2004**



DOE/BP-00013756-3

May 2004

This Document should be cited as follows:

*Knudsen, Curtis, "Reproductive Ecology of Yakima River Hatchery and Wild Spring Chinook; Yakima/Klickitat Fisheries Project Monitoring and Evaluation Report 3 of 7", 2003-2004 Annual Report, Project No. 199506325, 95 electronic pages, (BPA Report DOE/BP-00013756-3)*

Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

This report covers three of many topics under the Yakima/Klickitat Fisheries Project's Monitoring and Evaluation Program (YKFPME) and was completed by Oncorh Consulting as a contract deliverable to the Washington Department of Fish and Wildlife. The YKFPME is funded under two BPA contracts, one for the Yakama Nation and the other for the Washington Department of Fish and Wildlife (Contract number 00013756, Project Number 1995-063-25). A comprehensive summary report for all of the monitoring and evaluation topics will be submitted after all of the topical reports are completed. This approach to reporting enhances the ability of people to get the information they want, enhances timely reporting of results, and provides a condensed synthesis of the whole YKFPME.

# Reproductive Ecology of
# Yakima River
# Hatchery and Wild Spring Chinook

Annual Report 2003

Edited by:

**Curtis Knudsen**

Oncorh Consulting
2623 Galloway SE
Olympia, Washington 98501

Prepared for:

**Washington Department of Fish and Wildlife**
**600 Capitol Way North**
**Olympia, Washington 98501-1091**

**Project Number 1995-063-25**
Contract Number 00013756

**May 2004**

# Executive Summary

This is the third in a series of annual reports that address reproductive ecological research and comparisons of hatchery and wild origin spring chinook in the Yakima River basin. Data have been collected prior to supplementation to characterize the baseline reproductive ecology, demographics and phenotypic traits of the unsupplemented upper Yakima population, however this report focuses on data collected on hatchery and wild spring chinook returning in 2003; the third year of hatchery adult returns. This report is organized into three chapters, with a general introduction preceding the first chapter and summarizes data collected between April 1, 2003 and March 31, 2004 in the Yakima basin. Summaries of each of the chapters in this report are included below.

A major component of determining supplementation success in the Yakima Klickitat Fishery Project's spring chinook (*Oncorhynchus tshawytscha*) program is an increase in natural production. Within this context, comparing upper Yakima River hatchery and wild origin fish across traits such as sex ratio, age composition, size-at-age, fecundity, run timing and gamete quality is important because these traits directly affect population productivity and individual fish fitness which determine a population's productivity.

**Sex Ratio** - The female:male (F:M) ratios of upper Yakima River wild (1.6) and hatchery (1.5) origin fish collected at Roza Adult Monitoring Facility (RAMF) were not significantly different. In contrast, the F:M ratios of wild and hatchery origin fish in the spawning ground carcass sample were 1.5 and 2.6, respectively, and were significantly different. The F:M ratios of American and Naches spawning ground carcass samples were 2.0 and 1.6, respectively.

**Age Composition** – The majority of upper Yakima hatchery and wild origin fish returned as 3-year olds (49-50%), indicating a strong cohort from broodyear 2000. Age-4 fish made up 42% of the total wild origin returns and 27% of the hatchery origin returns. Age-5 fish made up 8 and 24% of the total wild and hatchery populations, respectively. Based on scale sampled carcass recoveries, age composition of the American River was 0, 8 and 92% age-3, -4 and –5, respectively. Naches system fish were 4, 21 and 75% age-3, -4 and –5, respectively.

**Sexual Dimorphism** – There were no significant Sex (Male vs. Female) effects in body size distributions of wild or hatchery age-4 American, Naches or upper Yakima River populations. American River, Naches and upper Yakima age-5 fish demonstrated significant sexual dimorphism with male being significantly larger than females.

**Size-at-Age** – As noted in both 2001 and 2002, returning age-3 and -4 hatchery fish in 2003 were significantly smaller than wild fish by just under 2 *cm* and 0.1 and 0.3 *kg*. There was no significant difference in size between age-5 hatchery and wild fish. Within hatchery returns there was no significant within-age difference in body size of age-3, -4

or -5 OCT and SNT returns. For wild populations, age-4 and –5 fish from the American River were larger than the Naches fish, which in turn were larger than upper Yakima fish of the same age. These wild origin populational differences in size-at-age are likely local adaptations developed in response to population-specific selection pressure from factors such as migration difficulty (gradient and flow), water temperature, and intra-sexual competition. The observed reductions in hatchery fish size-at-age of approximately 0.5 standard deviations will result in reduced fitness of naturally spawning hatchery fish and diminished natural productivity relative to wild fish. Counter selection in the wild will likely reduce the impacts on heritable traits in future generations.

**Run/Spawn Timing** - Median passage timing of adult hatchery and wild fish at RAMF differed by 1 day with hatchery fish passing earlier than wild fish. As in previous years, age-5's passed RAMF earliest, followed by age-4's, age-3's (lagging adult median passage date by 20-21 days) and finally age-2's. Mean spawn timing of upper Yakima River hatchery fish was significantly earlier by 6 days than wild fish, based on maturation/spawn dates at CESRF. As in past years, neither wild nor hatchery origin males nor hatchery females exhibited a significant linear relationship between passage date at RAMF and date of spawning at CESRF. Hatchery females did show a weak, significant positive correlation with passage date at RAMF, but it explained only 3% of the total variation in spawning date. Mean and median spawn timing was August 15 and 18, respectively, for the American River and September 13 and 14, respectively, for the Naches population based on carcass recoveries.

**Carcass Recovery Bias** – For adult hatchery origin fish, the F:M ratio at RAMF was significantly lower than the F:M ratio of spawning ground carcass recoveries, indicating that sex ratios estimated from hatchery origin carcass recoveries were biased due to female carcasses being recovered at higher rates than male carcasses. This was not true of wild origin fish. A comparison of the proportion of hatchery origin age-3 fish in the RAMF sample and the carcasses recovery sample also indicated that older, larger hatchery fish were recovered as carcasses at significantly higher rates than younger, smaller fish. This trend was not demonstrated in wild fish carcass recoveries. Within age classes, the mean POHP length of carcass recoveries did not differ significantly from fish sampled at RAMF. Thus, as in past years, carcass recovery length distributions accurately represent size-at-age.

**Fecundity and Fecundity/Female Size Relationship -** Age-4 hatchery females (3,907 eggs) were significantly less fecund than wild origin females (4,349 eggs). Age-5 wild (5,427 eggs) and hatchery (5,732 eggs) origin females did not differ significantly from each other, but were significantly more fecund than age-4 females. Fecundity and female body size showed similar significant strong, positive correlations in both hatchery and wild origin females. Age-5 females had stronger, positive correlations between female body size and fecundity not observed in previous years.

**Egg Weight** - There was no significant difference between mean egg weights of age-4 hatchery (0.184 g) and wild (0.188 g) or age-5 hatchery (0.200 g) and wild (0.208 g)

origin females. Age-4 eggs were significantly lighter than age-5 eggs by approximately 10%, similar to results for 2001 and 2002 returns.

**Gamete Weight and Reproductive Effort** - Reflecting the results for fecundity, gamete weight was significantly greater for wild age-4 females (mean= 812 *g*) compared to age-4 hatchery females (mean= 732 *g*). Age-5 hatchery females (mean= 1150 *g*) had greater mean gamete weight than wild age-5 females (mean= 1115 *g*), but the difference was not significant. Female Reproductive Effort (RE), the ratio of the weight of gametes to total body weight, did not differ significantly between age-4 or 5 females regardless of origin in 2003 (age-4 hatchery mean=0.190; wild females mean=0.197; age-5 wild mean=0.190; hatchery mean=0.193). This mirrors results found in 2001 and 2002.

**Egg-to-Fry Survival and Developmental Abnormalities** - There was no significant difference in egg-to-fry viability of hatchery (median =92.5%) and wild (median =92.1%) origin females. Both hatchery (median=0.2%) and wild (median=0.4%) origin fish had low percentages of abnormally developing fry with no significant difference between groups. These results are consistent with those from 2001 and 2002.

**Fry Size -** Wild fry (35 *mm*, 0.3 *g*, and 1.4 KD) were not significantly different in size from hatchery fry (35 *mm*, 0.3 *g* and 1.4 KD). There were strong positive relationships between fry size and egg weight for both wild and hatchery origin females. ANCOVA indicated that hatchery and wild fry slopes were not significantly different. As in 2001 and 2002, there were either no or weak positive female body size/fry size relationships, explaining at most 15% of the total variation in fry size.

**Fry Emergence Timing -** This research effort was initiated in 2002 and repeated in 2003 at CESRF. In 2002, median emergence timing and the range of emergence timing were not significantly different between hatchery and wild fry. In 2003, there was a significant difference, wild origin median emergence was 3 days later than hatchery and the wild range was 4 days shorter.

**Male Testes/Body Size Relationships -** Wild and Hatchery origin age-3 males did not exhibit significant differences in either mean testes weight, log(testes weight)/log(body size) relationships, or Reproductive Effort (RE). Testes weight was positively correlated with body size across all ages and age-2, -3 and -4 males each had significantly different mean testes weights. Age-2 males had a mean RE of 13%, which was significantly higher than in age-3 (6%) and -4 (6%) males. Thus, age-2 males allocated approximately twice the proportion of their total body weight toward gamete production than older anadromous males in order to compensate for their inordinate size disadvantage relative to older anadromous males during spawning.

**Redd Characteristics** - We measured redds of naturally spawning upper Yakima River hatchery and wild females constructed In-river and compared them to redds constructed in the CESRF experimental spawning channel. Redd measurements included water depth, velocity and substrate characteristics; and redd width and length and were associated with females of known origin and length. Thirteen hatchery- and 4 wild-origin

In-river redds and 12 hatchery- and 12 wild-origin Channel redds surveyed. There was no significant difference in fork lengths of naturally spawning hatchery and wild females. There were no significant differences in hatchery and wild origin redd measurement within the Channel. Because the small In-river wild-origin sample size resulted in low statistical power, we made no hatchery/wild comparisons between In-river redds. In only one of 37 tests were redd measurements significantly correlated with female fork length. These results were similar to 2002's. The CESRF experimental spawning channel redds were characterized by significantly lower velocity and shallower spawning habitat than that preferred by In-river spawning females resulting in smaller dimensions redds.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

# Table of Contents

Executive Summary.....iv

Table of Contents.....viii

General Introduction.....1

Chapter 1. Monitoring Phenotypic and Demographic Traits of Yakima River Hatchery and Wild Spring chinook: Spawner Traits……...3

Chapter 2. Monitoring Phenotypic and Demographic Traits of upper Yakima River Hatchery and Wild Spring chinook: Gametic and Juvenile Traits.....37

Chapter 3. Spawner and Redd Characteristics of Wild- and Hatchery-Origin Upper Yakima River Spring Chinook……...69

# General Introduction

This report is intended to satisfy two concurrent needs: 1) provide a contract deliverable from Oncorh Consulting to the Washington Department of Fish and Wildlife (WDFW), with emphasis on identification of salient results of value to ongoing Yakima/Klickitat Fisheries Project (YKFP) planning, and 2) summarize results of research that have broader scientific relevance. This is the third in a series of reports that address reproductive ecological research and monitoring of spring chinook in the Yakima River basin. This annual report summarizes data collected between April 1, 2003 and March 31, 2004.

Supplementation success in the Yakima Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program is defined as increasing natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack et al. 1997). Within this context demographics, phenotypic traits, and reproductive ecology have significance because they directly affect natural productivity. In addition, significant changes in locally adapted traits due to hatchery influence, i.e. domestication, would likely be maladaptive resulting in reduced population productivity and fitness (Taylor 1991; Hard 1995). Thus, there is a need to study demographic and phenotypic traits in the YKFP in order to understand hatchery and wild population productivity, reproductive ecology, and the effects of domestication (Busack et al. 1997). Tracking trends in these traits over time is also a critical aspect of domestication monitoring (Busack et al. 2002) to determine whether trait changes have a genetic component and, if so, are they within acceptable limits. Each chapter of this report deals with monitoring phenotypic and demographic traits of Yakima River basin spring chinook comparing hatchery and wild returns in 2003; the third year of adult hatchery returns. The first chapter deals specifically with adult traits of American River, Naches basin (excluding the American River), and upper Yakima River spring chinook, excluding gametes. The second chapter examines the gametic traits and progeny produced by upper Yakima River wild and hatchery origin fish. In the third chapter, we describe work to characterize and compare redds of naturally spawning wild and hatchery fish in the upper Yakima River and in an experimental spawning channel at CESRF.

The chapters in this report are in various stages of development and should be considered preliminary unless they have been published in a peer-reviewed journal. Additional fieldwork and/or analysis is in progress for topics covered in this report. Readers are cautioned that any preliminary conclusions are subject to future revision as more data and analytical results become available.

# Acknowledgments

We would like to thank Bonneville Power Administration for financially supporting this work. In addition, we could not have completed this work without the

help and support of many individuals during 2003/2004. We have tried to recognize each of them either on title pages or in acknowledgments within each chapter of this report.

# References


Busack, C., B. Watson, T. Pearsons, C. Knudsen, S. Phelps and M. Johnston. 1997. Spring Chinook Supplementation Monitoring Plan. Report to Bonneville Power Administration, Publ. No. DOE/BP 64878-1. 185 pp.

Busack, C., S. Schroder, and C. Knudsen. 2002. YKFP Spring Chinook Domestication/Monitoring Designs. Pages 10-28 in *Yakima/Klickitat Fisheries Project Genetic Studies*. BPA Annual Report 2001.

Hard, J. 1995. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. Amer. Fish. Soc. Sym. 15:212-225.

Schroder, S., C. Knudsen, B. Watson, T. Pearsons, S. Young, and J. Rau. 2002. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2001 Annual Report.

Taylor, E. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

# Chapter 1

# Monitoring Phenotypic and Demographic Traits of Yakima River Hatchery and Wild Spring Chinook: Spawner Traits

Prepared by:

Curtis M. Knudsen[1], Steve L. Schroder[2], Mark V. Johnston[3],

Todd N. Pearsons[4], Jason A. Rau[5], Charles R. Strom[5] and Mike L. Hamlin[4]

[1] Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

[2] Washington Department of Fish and Wildlife, 600 Capitol Way North
Olympia, WA 98501-1091

[3] Yakama Nation, P.O. Box 151, Toppenish, WA 98948

[4] Washington Department of Fish and Wildlife, 201 N. Pearl Street
Ellensburg, WA 98926

[5] Yakama Nation, Cle Elum Supplementation and Research Facility
Cle Elum, WA 98922

# Abstract

A major component of determining supplementation success in the Yakima Klickitat Fishery Project's spring chinook (*Oncorhynchus tshawytscha*) program is an increase in natural production. Within this context, comparing upper Yakima River hatchery and wild origin fish across traits such as sex ratio, age composition, size-at-age, fecundity, and run timing is important because these traits directly affect population productivity and individual fish fitness which determine a population's productivity. In addition, comparisons of these traits across the three putative wild populations in the Yakima River basin: American River, Naches, and upper Yakima River, help us identify and understand how local adaptations have uniquely shaped each population.

**Sex Ratio** - The female:male (F:M) ratios of upper Yakima River wild (1.6) and hatchery (1.5) origin fish collected at Roza Adult Monitoring Facility (RAMF) were not significantly different. In contrast, the F:M ratios of wild and hatchery origin fish in the spawning ground carcass sample were 1.5 and 2.6, respectively, and were significantly different. The F:M ratios of American (2.0) and Naches (1.6) spawning ground carcass samples were more similar to the upper Yakima population in 2003 and is due at least in part to the significantly modified carcass recovery methodology used in the upper Yakima River in 2003. Visual sexing of fish at RAMF identified females more accurately (99% correct) than males (66% correct) resulting in a significant overestimate of the proportion of returning females

**Age Composition** – In 2003, the majority of upper Yakima hatchery and wild origin fish returned as 3-year olds (49-50%) indicating the relatively strong cohort from broodyear 2000. Age-4 fish made up 42% of the total wild origin returns and 27% of the hatchery origin returns. Age-5 fish made up 8 and 24% of the total wild and hatchery populations, respectively. Linear discriminant function analysis was used to classify wild upper Yakima fish into 3-, 4- and 5-year-old age classes with 97, 85, and 90% classification accuracy, respectively. Hatchery fish were classified with a separate discriminant function with 100, 89, and 91% classification accuracy for 3-, 4- and 5-year olds, respectively. Based on scale sampled carcass recoveries, age composition of the American River was 0, 8 and 92% age-3, -4 and –5, respectively. Naches system fish were 4, 21 and 75% age-3, -4 and –5, respectively.

**Sexual Dimorphism** – In 2003, there were no significant Sex (Male vs. Female) effects in body size of wild or hatchery age-4 American, Naches or upper Yakima River populations. American River, Naches and upper Yakima age-5 fish demonstrated significant sexual dimorphism. In these populations, mean male post-orbital hypural plate length (POHP) was significantly greater than female length. Paired length and weight samples from fish sampled first at RAMF and then 1-5 months later at CESRF, were compared. POHP lengths differed significantly between samples indicating that there was likely a problem with measurement calibration. Fork length increased significantly (5-6% in males and 4% in females) and body weight decreased significantly: 18 to 22% and 15 to 16% in males and females, respectively.

**Size-at-Age** – As noted in 2001 and 2002, returning age-3 and -4 hatchery fish in 2003 were significantly smaller than wild fish by just under 2 *cm*. Three- and 4-year old hatchery origin fish weighed 0.1 and 0.3 *kg* less than wild fish of the same age, respectively. There was no significant difference in size between age-5 hatchery and wild fish. Within hatchery returns there was no significant within-age difference in body size of age-3, -4 or -5 OCT and SNT returns. Consistent with previous published reports, age-4 and –5 fish from the American River were larger than the Naches fish, which in turn were larger than upper Yakima fish of the same age. These wild origin populational differences in size-at-age are likely local adaptations developed in response to population-specific selection pressure from factors such as migration difficulty (gradient and flow), water temperature, and intra-sexual competition. The observed reductions in hatchery fish size-at-age of approximately 0.5 standard deviations will result in reduced fitness of naturally spawning hatchery fish and diminished natural productivity relative to wild fish. Counter selection in the wild will likely reduce the impacts on heritable traits in future generations.

**Run/Spawn Timing -** Median passage timing of adult hatchery and wild fish at RAMF differed by 1 day with hatchery fish passing earlier than wild fish. As in previous years, age-5's passed RAMF earliest, followed by age-4's, age-3's (lagging adult median passage date by 20-21 days) and finally age-2's. Mean spawn timing of upper Yakima River hatchery fish was significantly earlier by 6 days than wild fish, based on maturation/spawn dates at CESRF. As in past years, neither wild nor hatchery origin males nor hatchery females exhibited a significant linear relationship between passage date at RAMF and date of spawning at CESRF in 2003. Hatchery females did show a weak, significant positive correlation with passage date at RAMF, but it explained only 3% of the total variation in spawning date. Mean and median spawn timing was August 15 and 18, respectively, for the American River and September 13 and 14, respectively, for the Naches population based on carcass recoveries. The spawn timing of each population is likely a local adaptation in response to water temperatures during incubation. American, and to a lesser extent Naches, fish experience cooler water temperatures because of their higher elevation spawning habitat. Since fry emergence occurs in synchrony across all Yakima River populations, the higher elevation populations must spawn earlier in order for eggs to accumulate sufficient temperature units to emerge at the appropriate time.

**Carcass Recovery Bias** – For adult hatchery origin fish, the F:M ratio at RAMF was significantly lower than the F:M ratio of spawning ground carcass recoveries, indicating that sex ratios estimated from hatchery origin carcass recoveries were biased due to female carcasses being recovered at higher rates than male carcasses. This was not true of wild origin fish. A comparison of the proportion of hatchery origin age-3 fish in the RAMF sample and the carcasses recovery sample also indicated that older, larger hatchery fish were recovered as carcasses at significantly higher rates than younger, smaller fish. This trend was not demonstrated in wild fish carcass recoveries. Within age classes, the mean POHP length of carcass recoveries did not differ significantly from fish

sampled at RAMF. Thus, as in past years carcass recovery length distributions accurately represent size-at-age.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

# Introduction

Supplementation success in the Yakima Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program has been defined as an increase in natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack et al. 1997). Heritable quantitative traits, such as body size and size-at-age, are important to monitoring because these traits reflect local adaptations made by each population to selection pressures from their environment and bears directly on each population's productivity and fitness.

Changes in phenotypic and demographic traits due to hatchery influences (domestication) can have a genetic or environmental cause or be a complex combination of both (Hard 1995; Kinnison et al 2001; Quinn et al. 2001; Su et al. 2002). Significant changes in locally adapted traits due to domestication would likely be maladaptive in the wild, reducing reproductive success resulting in lower population productivity and fitness (Taylor 1991; Fleming and Gross 1993; Hard 1995; Fleming and Petersson 2001; Lynch and O'Hely 2001). A change in a trait that is random with respect to any heritable trait's distribution, but results in a reduction in fitness will not generate a genetic response in subsequent generations and population's productivity is reduced for only a single generation. In such cases, progeny produced from naturally spawning cultured fish should suffer no reduction in reproductive success when they spawn. Irrespective of underlying causes, body size affects a female's ability to compete in the wild for nest sites and construct and guard redds (Schroder 1982; van den Berghe and Gross 1984; van den Berghe and Gross 1989; Foote 1990), influences redd vulnerability to scour during flood events (van den Berghe and Gross 1989; Steen and Quinn 1999) and directly influences fecundity (Fleming and Gross 1990; Beacham and Murray 1993; Knudsen et. 2002). Body size can also influence spawning distribution by affecting the ability of fish to colonize more distant or higher elevation spawning areas (Beacham and Murray 1993; Kinnison et al. 2001) and larger portions of river systems (Rogers 1987; Blair et al. 1993; Hendry and Quinn 1997). Lower mean body weight can reduce the average carcass biomass returning to the natal basin, reducing exogenous nutrients utilized by rearing juveniles (Bilby et al. 1996). Changes in demographic/life history traits, such as a reduction in age classes or sex ratio, also have direct impacts, reducing a population's phenotypic variation, total annual egg production and effective size (Nunney 1991). In addition, significant changes in spawn timing can shift fry emergence timing outside the locally adapted temporal window resulting in reduced fry survival (Brannon 1987; Beacham and Murray 1993; Quinn et al. 1995; Hendry et al. 1998; Smoker et al. 1998; Beer and Anderson 2001; Quinn et al. 2002).

Hatchery origin Pacific salmon have been shown to exhibit lower reproductive success than wild fish in some studies (Reisenbichler and McIntyre 1977; Chilcote et al. 1986; Leider et al. 1990; Fleming and Gross 1992, 1993). Documenting changes in traits related to productivity and fitness, whether genetically or environmentally driven, contributes to our understanding of the immediate impacts of supplementation. In addition, tracking trends in these traits over time is an important aspect of the YKFP's

domestication selection monitoring effort (Busack et al. 2002) designed to determine whether there is a significant genetic component in observed trait changes.

We begin this report by describing three sets of biological data collected from hatchery and wild origin spring chinook returning to the upper Yakima River and describe changes in length and body weight due to secondary sexual development between passage at Roza Adult Monitoring Facility (RAMF) and spawning, analyze sexing accuracy at RAMF and compare estimated sex ratios. Next, we compare hatchery and wild origin fish returning in 2003 over the following traits: age composition, size-at-age, passage timing at RAMF, and spawning timing as represented by the temporal distributions in carcass recoveries or spawn timing at Cle Elum Supplementation Research Facilty (CESRF). We also make comparisons of age composition, size-at-age, and spawning timing between upper Yakima River, Naches, and American River wild spring chinook populations. Finally, we examined bias in carcass recovery samples. In the second chapter of this report, we compare the reproductive traits, gametes, and progeny produced from hatchery and wild origin upper Yakima River spring chinook returning in 2003.

## Methods and Materials

### Study Populations

Three genetically distinct wild spring chinook substocks have been identified in the Yakima River basin (Busack and Marshall 1991; unpublished DNA analyses by WDFW's Genetics Lab, S. Young): the upper Yakima River, Naches system (including the Naches River, Little Naches River, Rattlesnake River and Bumping River) and the American River (a tributary of the Naches River; Fig. 1). These three populations also exhibit differences in life history and demographic traits (Major and Mighell 1969; Fast et al. 1991; Knudsen 1991; Knudsen et al. 2002). The following analyses focus primarily on the upper Yakima River population spawning upstream of RAMF, the population targeted for supplementation under the YKFP (Busack et al. 1997), but also includes comparisons between the upper Yakima, American and Naches populations. The Naches population has been proposed as a wild control population for the YKFP's Domestication Monitoring Program (Busack et al. 2002).

There are three sets of biological data we examined representing spring chinook returning to the upper Yakima River above RAMF, located 40 kilometers upstream of Yakima (Fig. 1). All fish passing upstream must move through the adult trap at RAMF. The first data set represents hatchery origin fish sampled as they pass RAMF. After being processed, these fish are immediately released back into the river to complete their spawning migration. The second set represents both hatchery and wild origin fish collected at RAMF for use at the Cle Elum Supplementation and Research Facility (CESRF) as either broodstock or experimental subjects in reproductive success studies. These fish are referred to as the CESRF samples and were initially sampled at RAMF and then held to maturity at CESRF where they were again sampled at spawning. The third

dataset represents in-river carcass recoveries of hatchery and wild origin fish collected on the spawning grounds. All data representing the American River and Naches populations come from spawning ground carcass recoveries.

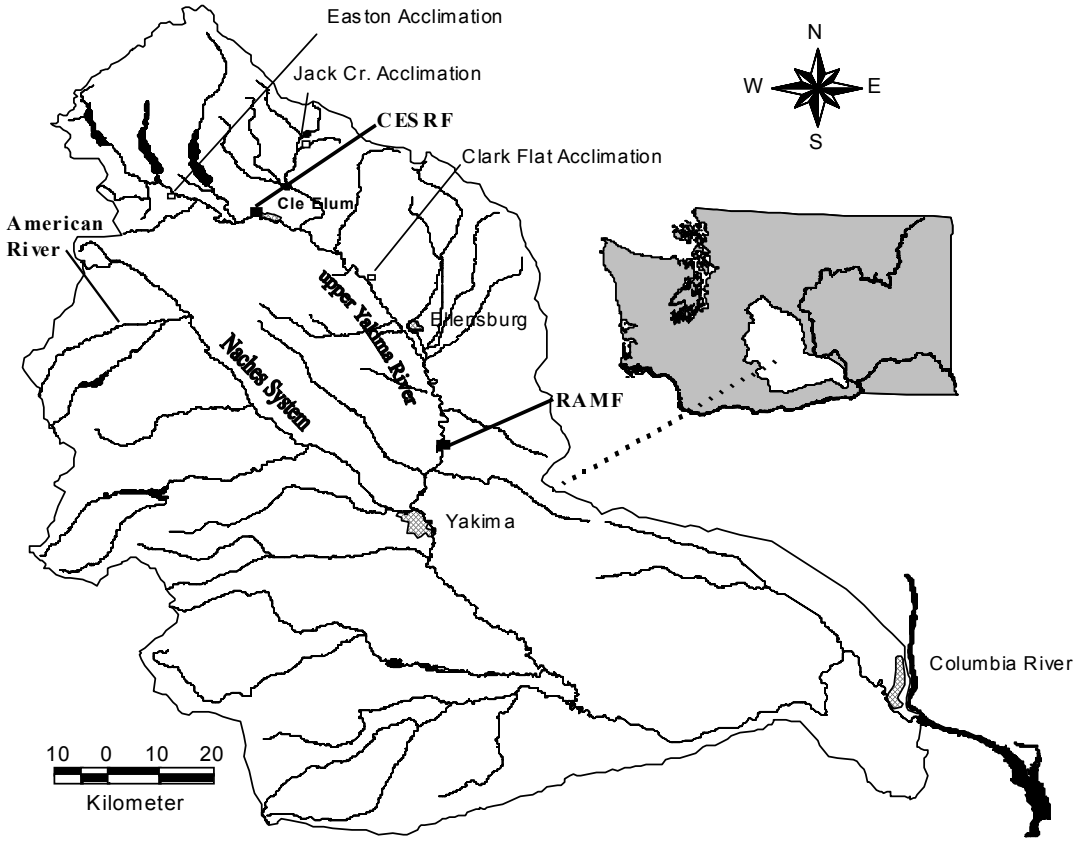



**Figure 1. Yakima River basin showing the upper Yakima River, Roza Adult Monitoring Facility (RAMF), the Cle Elum Supplementation Research Facility (CESRF), Naches system and American River.**

Hatchery Fish at RAMF

The largest and most comprehensive sampling of upper Yakima hatchery spring chinook occurs at RAMF as fish move upstream between April and September (Sampson and Fast 2001). Data from these hatchery origin fish are used to represent the population's age composition, size-at-age, and passage timing at RAMF. Hatchery origin fish are identified as they pass through RAMF either by the presence of a Coded-Wire Tag (CWT), which activates a sensor tripping a hydraulic gate, or by the visual identification of the missing clipped adipose fin. All hatchery juvenile releases were adipose fin clipped and tagged with at least one CWT.

Hatchery and Wild Origin Fish Held at CESRF

In 2003 wild and hatchery origin fish were collected at RAMF as broodstock. Data collected from the wild origin fish are used to represent the wild population's age

composition, size-at-age, sex ratio, run timing at RAMF and spawn timing. The estimated total number of broodstock needed for full hatchery production is based on the mean historical sex ratio, age composition, age-specific broodstock fecundity while captive (including prespawning egg losses), adult prespawning mortality, BKD infection rates, and in-culture egg-to-smolt survival (B. Bosch, YN, pers. comm.). Broodstock are selected at RAMF randomly with respect to sex. A fixed proportion of the total broodstock is collected each week over the entire run based on weekly mean historical passage proportions at RAMF with the first week beginning on the day the first fish passes RAMF. Using this methodology, broodstock take is allocated over the entire run, weighted by historical passage timing. This ensures that significant over- and under-collecting of broodstock does not occur, as can happen when the broodstock collection goal is a fixed percentage of the predicted run and actual run size significantly deviates from the prediction. Weekly wild-origin broodstock collections are typically equally divided over 4 days within each week when 9 or more fish were collected. For example, if 12 fish are scheduled for collection that week, then 3 are taken per day over 4 consecutive days. When weekly collections are less than 9 fish, they occur over 1-3 days. As long as the current year's run does not deviate significantly from historical run timing trends, broodstock collections will be well represented over the entire run. Weekly cumulative run size and broodstock collection during 2003 for wild and hatchery origin adults are shown in Figure 2.

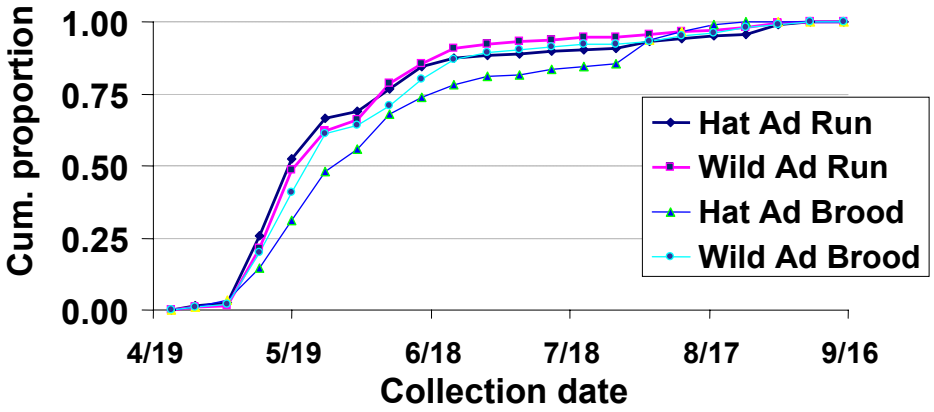



**Figure 2. Weekly run timing in 2003 for adult hatchery (Hat Ad Run) and wild (Wild Ad Run) origin fish. Run values are the weekly cumulative proportion of the run passing RAMF. The "Hat Adult Brood" and "Wild Adult Brood" values are the weekly cumulative proportions of hatchery and wild fish taken for broodstock in 2003.**

Collection of wild origin age-3 jacks for broodstock is handled differently than adults. The proportion of jacks collected for broodstock is based on the historical geometric mean proportion of jacks returning within a cohort. There are significant differences in size between age-3 and age-4 fish and it is possible to separate these two ages with 4% error or less at RAMF based on post-orbital hypural plate length (POHP) and body weight (see analyses below and Knudsen et al. 2002; Knudsen et al. 2003). The estimated proportion of wild jacks returning is based on length criteria visually estimated

as fish pass RAMF. There is an unknown error rate involved in this estimation technique due to the short time fish are observed as they pass down an inclined chute and no rigorous test of this method has occurred. Additional jacks beyond those needed for broodstock were collected in 2003 for use in reproductive success studies at CESRF.

Biological sampling of the wild origin CESRF sample at RAMF included length (FL and POHP), body weight, scale samples, passage date and a provisional visual sex classification. In addition, all fish transported to CESRF (either hatchery and wild) are tagged intramuscularly in the pelvic girdle with a uniquely coded 18 mm Passive Integrated Transponder (PIT) tag (Johnston and McCutcheon *in prep*.) and their history from the time of capture through pre-spawning mortality or successful spawning is tracked. At spawning, length (fork length [FL] and POHP), body weight, and the sex of each fish are again recorded. This data, along with gametic traits collected during spawning, can then be linked back to that fish's biological data collected at RAMF.

Artificial spawning at CESRF occurred over a five-week period from September 4$^{th}$ through October 8$^{th}$. Additional wild and hatchery origin fish collected at RAMF for use in reproductive success studies or that died prior to spawning, were sampled in the same manner as broodstock and are included in the age composition, sex ratio, spawn timing, and size-at-age analyses below, as appropriate. The maturation timing of artificially spawned hatchery and wild fish were compared using ANOVA. In 2003, a total of 440 wild- and 140 hatchery-origin fish were collected for both broodstock and reproductive success studies.

Hatchery and Wild In-river Carcass Recoveries

The third dataset is made up of hatchery and wild origin carcasses recovered in the Naches subbasin by YN personnel during the course of weekly spawning ground surveys made in the Naches River basin (Fig. 1) between July and September and NMFS personnel in the upper Yakima River (A. Dittman, NMFS, pers. comm.). Origin (hatchery/wild based on the presence of marks), recovery date and stream reach are recorded for each carcass sampled. Sex, length (POHP) and scale samples for age are collected on a subsample of carcasses. In 2003, carcasses were recovered in the American River between July 29 and September 2 (n=233), in the Naches system between August 4 and September 26 (n=163), and between September 30 and October 10 in the upper Yakima River (n=163 wild- and n=486 hatchery-origin). Carcass sampling in the upper Yakima River by National Marine Fisheries Service personnel was focused primarily on estimating spatial distribution of naturally spawning hatchery origin fish from the YKFP's three acclimation sites (A. Dittman, NMFS, pers. comm.).

**Traits**

Sex Ratio

Estimates of adult Female:Male (F:M) ratios were calculated based on fish collected at RAMF (excluding age-3 jacks) and held at the CESRF facility. The sex of

these fish could be identified unambiguously by *post mortem* inspection of the body cavity. In addition, the accuracy of RAMF visual sex classifications of live fish, made 1-5 months prior to spawning, were determined by comparing them to the CESRF *post mortem* sexing of the same fish identified by the PIT tag codes. Comparisons of sex ratios between groups were made using a $X^2$-test and Yates correction when appropriate.

Age Composition

Useable scale samples were collected from 1,215 fish age-3 or greater passing RAMF in 2003 representing 31.6% of the total run. Scales were placed on gummed cards and labeled so that the PIT tag number and other biological data collected could be linked to the fish's age. Ages are designated as the number of years from the year of conception (broodyear) to return year. Thus, a fish produced from parents spawning in the fall of 1998 and returning in 2003 is designated an age-5 fish. Under this convention, precocious males (nonanadromous males maturing in their first [wild only] or second [wild and hatchery] year) are designated age-1 and age-2, respectively. Returning spring chinook in the Yakima River are essentially all yearling outmigrants based on scales (J. Sneva, WDFW, pers. comm.). Age composition of the wild adult ($\geq$ age-4) population was estimated from fish held at CESRF (n=406 of which 8 could not be aged), while the wild age-3 jack proportion was estimated based on the visual estimations of length as fish passed through RAMF. Acetate impressions were made from the scale cards and ages determined by examining the impressions using a microfiche reader. Two scale analysts: T. Swan, YN, and J. Sneva, WDFW, independently aged all scales. Carcass samples, where the sex of fish was confirmed by examining body cavities, were compared to samples collected at RAMF using a $X^2$-test to determine whether there was bias caused by unequal carcass recovery rates of different age classes and sexes. Age compositions of Naches system (n=159) and American River (n=225) populations were estimated from scale sampled carcass recoveries.

Sexual Dimorphism in Body Size and Development of Secondary Sex Characteristics

Sexual dimorphism in body size has often been observed in Pacific salmon (e.g. Quinn and Foote 1994; Knapp and Vrendenburg 1996; Knudsen et al. in prep.) and can be an indicator of the intensity of sexual selection, particularly in males (Fleming and Gross 1994). However, it can also be strongly affected by selection from size and sex selective fisheries (Beaty 1996; Hamon et al. 2000; Knudsen et al. in prep.). We examined the 2003 CESRF data set (sex confirmed by *post mortem* inspection) and compared length (POHP) and body weight differences between upper Yakima River age-4 and age-5 adults due to Sex (Male vs. Female) effects using ANOVA. The two age classes were analyzed separately based on results from 2001 and 2002 showing only age-5 fish had a significant Sex effect (Knudsen et al. 2002; Knudsen et al. 2003). If no significant Sex effect was observed, then body size data were pooled across sexes in subsequent analyses. We also analyzed age-4 and –5 carcass recoveries from Naches and American River wild populations for sexual dimorphism. In those analyses, we used a 2-way ANOVA to estimate Age (4 vs. 5), Sex (Male vs. Female) and interaction effects.

After entering the Columbia River, maturing spring chinook stop feeding and must rely on endogenous energy stores to sustain them. This, along with the development of secondary sexual traits and gametes, causes morphological changes in fish over time. We estimated to what extent upper Yakima River spring chinook body size changes between the time they pass RAMF and spawn by comparing the length and body weight of fish sampled when they passed RAMF and then again, 1 to 5 months later, when spawned at CESRF using paired-sample t-tests.

Size-at-Age

We used the CESRF samples in 2003 to compare hatchery and wild size-at-age using ANOVA. In addition, the accuracy with which age could be estimated from log transformed POHP and body weight was calculated from separate linear discriminant function analyses (Fisher 1936) of wild origin and hatchery-origin fish. Model significance was estimated using MANOVA and classification accuracy was estimated using a jackknife classification procedure (Efron 1982).

Length distributions of American, Naches and upper Yakima wild population carcass recoveries were compared using 2-way ANOVA estimating Age (4 vs 5) and Population (American vs Naches vs upper Yakima) effects.

Run/Spawn Timing

We examined the linear relationship between the date wild and hatchery origin fish were collected at RAMF and the date they were subsequently spawned at CESRF by regressing passage date at RAMF against spawning date at CESRF. The RAMF passage timing distributions of hatchery and wild origin fish were compared using a Kruskal-Wallis non-parametric ANOVA (K-W test; Zar 1984). Within hatchery fish, passage timing of the OCT and SNT treatment groups at RAMF were also compared with a K-W test. Comparison of hatchery and wild spawn timing was done using broodstock spawned at CESRF and fish placed into the CESRF spawning channel. Fish were selected for inclusion in the spawning channel based on being fully ripe (expression of fully developed gametes) and their "spawn date" was recorded as the day they were placed into the channel, since they would have been selected and used as broodstock on that day. Comparisons were made using a 2-way ANOVA (Origin and Sex effects).

Carcass Recovery Bias

RAMF samples are collected proportionately from throughout the run (Fig. 2) and without regard to sex. All fish passing upstream must move through RAMF and so are equally subject to sampling. For these reasons we believe RAMF samples are representative of both hatchery and wild origin fish naturally spawning above RAMF. If naturally spawning fish of different ages, sizes and sex are equally likely to be recovered as carcasses, then the proportion of fish in each sex/age class observed RAMF trap should be equal to the proportions observed in the carcass recovery sample. Carcass recovery rates not equal to RAMF across size and sex, then age composition and sex ratio

estimates indicate biased. We estimated whether bias occurred in 2003 upper Yakima spring chinook by comparing size-at-age, age composition and the F:M ratio of fish passed upstream at RAMF to estimates generated from in-river carcasses recoveries using $X^2$ analysis.

All statistical analyses were done using the SYSTAT 8.0 software package (SPSS 1998).

# Results

## Sex Ratio

CESRF and Spawning Ground Sex Ratios

The adult female:male (F:M) ratios of upper Yakima River wild (1.6) and hatchery (1.5) origin fish collected at RAMF were not significantly different ($X^2$=<0.001 with Yates correction, p=1.00). However, when carcasses are compared, hatchery (F:M=2.6) origin fish have significantly more females than wild fish (F:M=1.5; $X^2$=4.03 with Yates correction, p=0.045). The proportion of jacks returning in 2003 was approximately 50% with 98% or more of that age class male (see Table 2 below; Kassler *et al.* 2004). With jacks included, the sex ratios are hatchery F:M 0.83 and wild F:M 0.63. In 2003, the adult F:M ratios of the upper Yakima population spawning ground carcass samples were more similar to American and Naches than in previous years and is likely due to significant changes in the upper Yakima carcass recovery methodology (see Carcass Recovery Bias section below). For this reason upper Yakima sex ratios may not be comparable to previous year's results.

Table 1. Classification matrix showing the accuracy of adult sex identifications at RAMF in 2003 based on visual classification of fish. Each cell shows the number of fish of known sex ("Correct sex" determined from carcasses) that were classified as male or female (Classification result). The percentage of fish classified into each category is in parentheses. "Overall mean accuracy" is the mean of the "Percentage correctly classified". Hatchery and wild fish were combined for this analysis.

| Correct sex | Classification result | | Percentage correctly classified |
|---|---|---|---|
| | Male | Female | |
| Male | 132 (66.0%) | 68 (34.0%) | 66.0% |
| Female | 3 ( 1.2%) | 249 (98.8%) | 98.8% |
| | | Overall mean accuracy | 82.4% |

Accuracy of Visual Sexing at RAMF

Table 1 shows the overall classification accuracy of visually sexing adult fish (age 4 or older) at RAMF in 2003. As in past years, females are more accurately identified (99% correctly identified) than males (66% correctly identified). This creates bias in sex ratios by over estimating the proportion of females. Inaccurate sexing also creates

problems when analyzing traits of individual fish in which sex is an important covariate, such as age, size, and potential egg deposition.

**Age Composition**

Upper Yakima River Wild and Hatchery Origin

Age composition of adult (age-4 and older) wild origin fish was estimated from fish collected at RAMF and taken to CESRF (n=451). This includes fish selected for broodstock, reproductive success studies and mortalities occurring prior to spawning. These fish were sexed *post mortem* and parsed into age classes by sex (Table 2). A very

Table 2. Age composition and sex of 2003 upper Yakima River wild and hatchery origin spring chinook based on scale, biological and mark/tag samples collected at RAMF and CESRF.

| Origin | Age | Overall %[a] | % Male[b] | % Female[b] |
|---|---|---|---|---|
| Upper Yakima River Wild | 3 | 49.7 [c] | 49.7 ( 37) | 0.0 ( 0) |
| | 4 | 41.9 (330) | 15.1 ( 92) | 26.8 (164) |
| | 5 | 8.4 ( 66) | 3.2 ( 19) | 5.2 ( 31) |
| | | Adult Total | 36.3 (111) | 63.7 (195) |
| Up. Yakima River Hatchery | 3 | 49.3 [c] | 49.3 ( 17) | 0.0 ( 0) |
| | 4 | 27.0 (608) | 9.2 ( 16) | 17.8 ( 31) |
| | 5 | 23.7 (533) | 10.8 ( 15) | 12.9 ( 18) |
| | | Adult Total | 38.7 ( 31) | 61.3 ( 49) |

[a] The ages used in the "Overall %" were determined from scales and tags or marks.

[b] The proportion of the "Overall %" in an age class allotted to each sex was based on RAMF fish of that age taken to CESRF and examined *post mortem*.

[c] Jack proportions based on visual estimates of length as fish pass RAMF and assumes all jacks are male. Other age percentages are adjusted to account for the jack estimate.

Table 3. Jackknifed classification matrices from linear discriminant function analyses estimating the ageing accuracy of wild and hatchery origin spring chinook based on RAMF log transformed POHP length and body weight in 2003. "Age classification" cells show the number of fish of known age that were classified as age-3, -4 or -5. The percentage classified into each category is in parentheses. Overall accuracy is the mean of the "Percent correctly classified" values.

| Origin | True age | Age classification – N (%) | | | Percent correctly classified |
|---|---|---|---|---|---|
| | | Age 3 | Age 4 | Age 5 | |
| Wild | Age 3 | 36 (97.3%) | 1 ( 2.7%) | 0 ( 0.0%) | 97.3% |
| | Age 4 | 3 ( 1.2%) | 220 (84.9%) | 36 ( 13.9%) | 84.9% |
| | Age 5 | 0 ( 0.0%) | 5 ( 9.6%) | 47 (90.4%) | 90.4% |
| | | | | Overall accuracy | 90.9% |
| | | | | | |
| Hatchery | Age 3 | 393 (99.7%) | 1 ( 0.3%) | 0 ( 0.0%) | 99.7% |
| | Age 4 | 1 ( 0.4%) | 227 (88.7%) | 28 (10.9%) | 88.7% |
| | Age 5 | 0 ( 0.0%) | 20 ( 9.3%) | 196 (90.7%) | 90.7% |
| | | | | Overall accuracy | 93.3% |

strong age-3 cohort (broodyear 2000) represented 50% of the returns in 2003. This differed from most years when the majority of wild origin fish are 4-year olds. In 2003 only 42% of the returns were age-4 with a relatively strong 8% returning at age-5. Hatchery fish were also predominately age-3 (49%), but had a higher percentage of age-5's (24%) and fewer age-4's (27%) than wild fish. The age-5 hatchery cohort from broodyear 1998 has returned at very high rates.

Linear discriminant function analysis was used to estimate the accuracy with which wild and hatchery origin fish of known age (based on scales or marks/tags) could be classified. Log transformed POHP length and body weight of fish collected at CESRF were used to classify fish into age classes. Males and females were pooled within each age class. Jackknifed classification accuracies for wild origin fish were 97, 85, and 90% for 3-, 4- and 5-year olds, respectively (Table 3; Fig. 3A; MANOVA; *df* 4, 688; $p<0.001$), with the majority of errors occurring between age-4 and –5 classes. Jackknifed classification accuracies for hatchery origin fish were 100, 89, and 91% for 3-, 4- and 5-year olds, respectively (Table 3; Fig. 3B; MANOVA; *df* 4, 1724; $p<0.001$). The discriminant functions were used to assign ages to the other fish sampled for POHP and body weight at RAMF (Hatchery n=1558; Wild n=13) and these ages were used to calculate size-at-age and run timing at RAMF by age. Variation in body size, particularly body weight, increased with age causing heteroscedasticity. Log transformations were used to correct for unequal between-group variances so that the assumption of equal between-group variance-covariance matrices would not be violated.

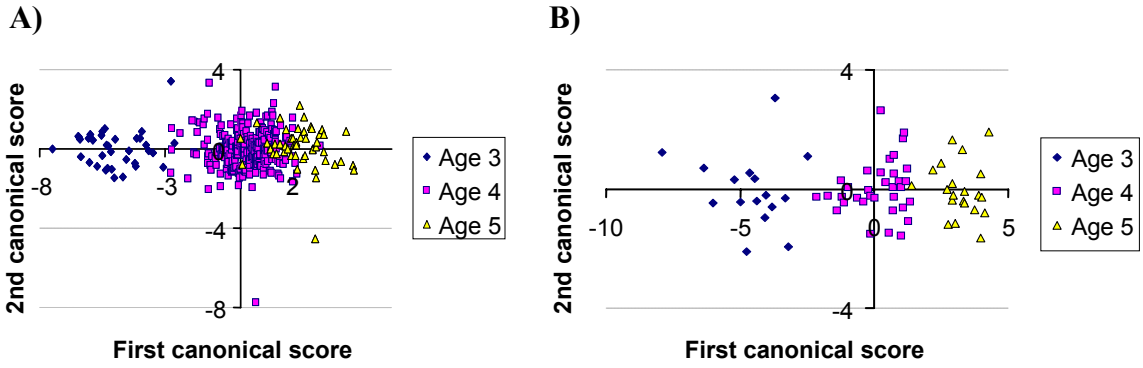



**Figure 3. canonical scores from a discriminant function analysis of A) Wild-origin and B) Hatchery –origin fish using log (POHP) and log (Body weight) as discriminators. Classification rates for wild and hatchery fish are given in Tables 3.**

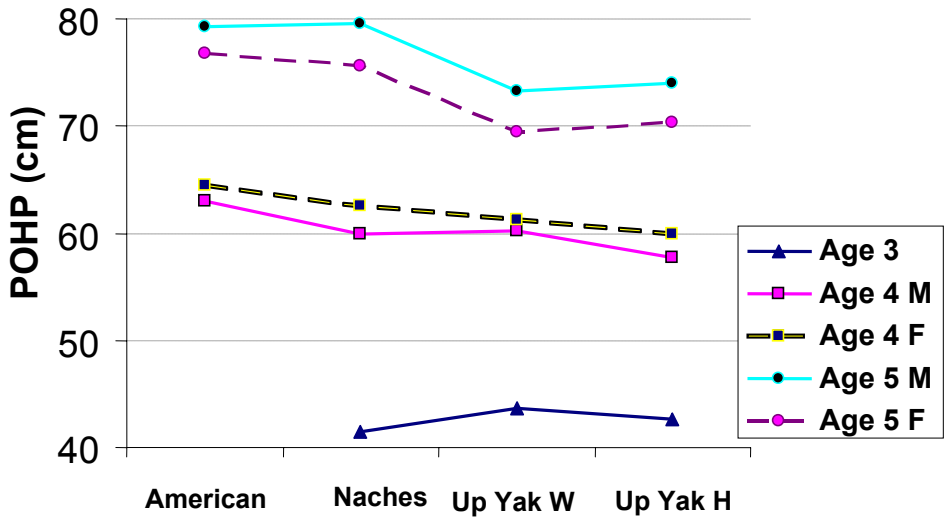



**Figure 4. Mean POHP length of age-3 (triangles), age-4 (squares) and age-5 (circles) American River, Naches system, and Yakima River wild populations by male (solid lines) and female (broken lines).**

Table 4. Age composition of 2003 American River and Naches wild and upper Yakima River hatchery and wild origin spring chinook based on scale samples collected from in-river carcass recoveries. Upper Yakima River carcass recovery data provided by A. Dittman, NMFS.

| Population | Sex | Age | N | Percent by sex | Overall percent |
|---|---|---|---|---|---|
| American River | Male | 3 | 0 | 0 | 0 |
| | | 4 | 6 | 8.1 | 2.7 |
| | | 5 | 68 | 91.9 | 30.2 |
| | Female | 3 | 0 | 0 | 0 |
| | | 4 | 12 | 7.9 | 5.3 |
| | | 5 | 139 | 92.1 | 61.8 |
| Naches system | Male | 3 | 5 | 2.1 | 3.1 |
| | | 4 | 15 | 78.7 | 9.4 |
| | | 5 | 44 | 19.1 | 27.7 |
| | Female | 3 | 1 | 0 | 0.6 |
| | | 4 | 19 | 67.2 | 12.0 |
| | | 5 | 75 | 32.8 | 47.2 |
| Upper Yakima Wild | Male | 3 | 78 | 69.6 | 47.9 |
| | | 4 | 25 | 22.3 | 15.3 |
| | | 5 | 9 | 8.0 | 5.5 |
| | Female | 3 | 1 | 2.0 | 0.6 |
| | | 4 | 37 | 72.5 | 22.7 |
| | | 5 | 13 | 25.5 | 8.0 |
| Upper Yakima Hatchery | Male | 3 | 171 | 64.5 | 35.3 |
| | | 4 | 49 | 22.4 | 10.1 |
| | | 5 | 45 | 17.0 | 9.3 |
| | Female | 3 | 4 | 1.8 | 0.8 |
| | | 4 | 94 | 42.9 | 19.4 |
| | | 5 | 121 | 55.3 | 25.0 |

American River and Naches

Based on scale sampled carcass recoveries, age composition from the American River was 0, 8 and 92% age-3, -4 and –5, respectively, while Naches system fish were 4, 21 and 75% age-3, -4 and –5, respectively (Table 4). The age-5 year class from brood year 1998 was especially strong and the age 4 year class was relatively low in both populations. The American River population again returned more age-5 fish than the Naches, as noted in earlier analyses (Major and Mighell 1969; Fast et al. 1991; Knudsen 1991), and the age compositions of these two populations were significantly different in 2003 ($X^2$=13.27; *df*=2; p=0.001). Upper Yakima River hatchery and wild carcass recoveries had higher than normal proportions of age 5 fish, 14 and 24%, respectively.

Table 5. Mean POHP length of American and Naches (carcass recoveries) and upper Yakima wild and hatchery origin (carcass and CESRF samples combined) spring chinook in 2003.

| Population | Sex | Age | POHP (*cm*) | sd | N |
|---|---|---|---|---|---|
| American River | Male | 3 | | | 0 |
| | | 4 | 63.0 | 7.0 | 6 |
| | | 5 | 79.4 | 5.1 | 68 |
| | Female | 3 | | | 0 |
| | | 4 | 64.3 | 3.1 | 12 |
| | | 5 | 76.7 | 3.9 | 139 |
| Naches system | Male | 3 | 41.4 | 4.4 | 5 |
| | | 4 | 61.5 | 6.4 | 15 |
| | | 5 | 79.2 | 4.5 | 44 |
| | Female | 3 | 56.3 | 7.4 | 2 |
| | | 4 | 62.8 | 5.0 | 19 |
| | | 5 | 75.7 | 3.5 | 75 |
| Upper Yakima wild | Male | 3 | 43.6 | 3.8 | 76 |
| | | 4 | 63.8 | 6.1 | 63 |
| | | 5 | 75.3 | 4.3 | 18 |
| | Female | 3 | 44.7 | 1.6 | 3 |
| | | 4 | 61.9 | 4.1 | 273 |
| | | 5 | 71.1 | 3.9 | 45 |
| Upper Yakima Hatchery | Male | 3 | 42.6 | 3.9 | 179 |
| | | 4 | 60.1 | 5.0 | 54 |
| | | 5 | 72.4 | 4.6 | 53 |
| | Female | 3 | 44.7 | 1.6 | 3 |
| | | 4 | 59.4 | 4.1 | 129 |
| | | 5 | 69.7 | 4.0 | 124 |

**Sexual Dimorphism and Development of Secondary Sex Characteristics**

Sexual Dimorphism

Mean POHP lengths of American, Naches and upper Yakima wild and hatchery populations by sex and age are given in Table 5 and Figure 4. We used a 1-way ANOVA to test for Sex effects (Male vs Female) in POHP length distributions (Table 6). Age-4 and –5's were analyzed separately because previous results showed that there were significant Sex effects for age-5 fish only (Knudsen *et al.* 2002; Knudsen *et al*. 2003). Age-3 females are so few in number ($\leq$2%) that no statistical comparison was made. As in 2001 and 2002, we found no significant Sex effects in age-4 hatchery or wild fish ($p \geq 0.270$), although females were slightly larger than males across all populations. Mean POHP lengths differed by less than 1 *cm*. There was a significant difference between the sexes in all age-5 populations ($p<0.001$), with males being approximately 3 *cm* longer on average than females.

Table 6. One-way ANOVA results for POHP length estimating Sex (male and female) effects from age-4 and age-5 wild and hatchery origin returns in 2003.

| Population | Type/Age | Source | Sums-of-Squares | df | Mean-Square | F-ratio | P-value |
|---|---|---|---|---|---|---|---|
| Upper Yakima Wild | Age 4 | Sex | 22.7 | 1 | 22.7 | 0.9 | 0.345 |
| | | Error | 1504.3 | 60 | 25.1 | | |
| | Age 5 | Sex | 222.0 | 1 | 222.0 | 13.7 | <0.001 |
| | | Error | 989.7 | 61 | 16.2 | | |
| Upper Yakima Hatchery | Age 4 | Sex | 23.9 | 1 | 23.9 | 1.2 | 0.270 |
| | | Error | 3527.9 | 181 | 19.5 | | |
| | Age 5 | Sex | 264.5 | 1 | 264.5 | 15.0 | <0.001 |
| | | Error | 3094.5 | 175 | 17.7 | | |
| American River | Age 4 | Sex | 6.3 | 1 | 6.3 | 0.3 | 0.599 |
| | | Error | 348.3 | 16 | 21.8 | | |
| | Age 5 | Sex | 315.0 | 1 | 315.0 | 16.5 | <0.001 |
| | | Error | 3905.1 | 205 | 19.0 | | |
| Naches | Age 4 | Sex | 14.7 | 1 | 14.7 | 0.5 | 0.503 |
| | | Error | 1024.9 | 32 | 32.0 | | |
| | Age 5 | Sex | 341.8 | 1 | 341.8 | 22.2 | <0.001 |
| | | Error | 1798.8 | 117 | 15.4 | | |

**Development of Secondary Sex Characteristics**

The difference (RAMF value-CESRF value) between paired lengths and weights from the same fish sampled first at RAMF and then again at CESRF 1-5 months later were analyzed to estimate changes in traits over time (Table 7). Fork length, POHP lengths and body weight showed significant changes in every paired sample (all ages and sexes $p<0.001$). The results for POHP length were in sharp contrast to 2002 when age 3 and 4 fish demonstrated no significant differences. We feel the POHP length differences are

likely an artifact of some mechanical problem in measurement, such as a poorly calibrated ruler at one of the facilities, and do not reflect true differences in body length. However, we cannot determine which facility, RAMF or CESRF, was in error. Fork length differences do reflect the development of the kype, a secondary sexual characteristic. Male FL increased by 5 to 6% and female FL increased by 4% on average during the 1-5 months fish were held at CESRF. Body weight consistently decreased over time.

Table 7. Mean differences between paired samples of fork length (FL), post-orbital hypural plate length (POHP) and body weight (BW) measured on the same fish at RAMF and then subsequently at CESRF. Differences were calculated as RAMF value minus CESRF value. Differences were compared to a null hypothesis of 0 difference (paired sample t-test; α=0.05; 2-tailed).

| Age | Sex | N | FL (cm) | POHP (cm) | BW (kg) |
|---|---|---|---|---|---|
| 3 | Male | 54 | -2.60** | 0.87** | 0.24** |
| 4 | Male | 108 | -4.08** | 1.24** | 0.64** |
| | Female | 295 | -3.29** | 1.09** | 0.60** |
| 5 | Male | 5 | -4.44** | 1.07** | 1.12** |
| | Female | 50 | -3.26** | 1.28** | 0.80** |

** indicates $p \leq 0.01$.
* indicates $p \leq 0.05$

**Size-at-age**

Hatchery and Wild Origin Returns

We made hatchery/wild comparisons by age class using a 1-way ANOVA testing for Origin effects. As had been observed in 2001 and 2002, wild fish were again larger than hatchery fish (Tables 8 and 9; Origin effects $p \leq 0.003$). Age-3 wild fish were 1.8 cm longer and 0.1 kg heavier than age-3 hatchery fish, while age-4 wild fish were 1.7 cm longer and 0.3kg heavier than hatchery fish.

Table 8. Two-way ANOVA results for log(POHP length) estimating Origin (wild/hatchery) and Age (3/4) effects.

| Source | Sums-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Origin | 0.025 | 1 | 0.025 | 20.583 | <0.001 |
| Age | 2.683 | 1 | 2.683 | 2220.465 | <0.001 |
| Origin*Age | 0.001 | 1 | 0.001 | 0.973 | 0.324 |
| Error | 1.138 | 942 | 0.001 | | |

Table 9. Two-way ANOVA results for log(body weight) estimating Origin (wild/hatchery) and Age (3/4) effects.

| Source | Sums-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Origin | 0.108 | 1 | 0.108 | 8.857 | 0.003 |
| Age | 23.257 | 1 | 23.257 | 1910.478 | <0.001 |
| Origin*Age | <0.001 | 1 | <0.001 | <0.1 | 0.935 |
| Error | 11.467 | 942 | 0.012 | | |

OCT vs SNT

There was only 0.1 cm and 0.03 kg difference between the OCT and SNT age-4 groups in 2003. Means for all age class and treatment groups are given in Table 10. There was no significant Treatment effect (OCT vs. SNT) found for POHP length ($p$=0.68) or body weight ($p$=0.93) and no Age*Treatment interaction effects were significant ($p \geq 0.30$; Tables 11 and 12).

Table 10. Summary statistics for body weight and POHP length of OCT and SNT by age class for returns in 2003. Biological data was collected at RAMF. Standard deviations are given in parentheses.

| Age | Treatment | Body weight (kg) | POHP length (cm) | N |
|---|---|---|---|---|
| 3 | OCT | 1.52 (0.44) | 41.8 (3.8) | 228 |
| | SNT | 1.55 (0.43) | 42.2 (3.6) | 118 |
| 4 | OCT | 4.37 (1.01) | 60.5 (4.5) | 100 |
| | SNT | 4.34 (0.92) | 60.6 (4.3) | 110 |
| 5 | OCT | 6.98 (1.02) | 72.1 (3.9) | 75 |
| | SNT | 6.66 (1.23) | 71.1 (3.9) | 71 |

Table 11. Two-way ANOVA results comparing log(body weight) estimating Treatment (OCT/SNT) and Age (3, 4 and 5) effects from RAMF recoveries.

| Source | Sums-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Treatment | 0.00292 | 1 | 0.00292 | 0.2348 | 0.683 |
| Age | 52.44916 | 2 | 26.22458 | 2105.6737 | <0.001 |
| Trt*Age | 0.02710 | 2 | 0.01355 | 1.0880 | 0.608 |
| Error | 8.66816 | 696 | 0.01245 | | |

Table 12. Two-way ANOVA results comparing log(POHP) lengths for Age (3/4/5) and Treatment (OCT/SNT) effects from on lengths collected at RAMF with sexes pooled.

| Source | Sums-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Treatment | 0.00001 | 1 | 0.00001 | 0.00800 | 0.929 |
| Age | 6.45285 | 2 | 3.22642 | 2727.87807 | <0.001 |
| Trt*Age | 0.00289 | 2 | 0.00144 | 1.22166 | 0.295 |
| Error | 0.82320 | 696 | 0.00118 | | |

American River and Naches system

American River and Naches mean POHP lengths by sex and age are shown in Table 5 and Figure 4. Age-4 fish from the American River were larger than Naches fish, while upper Yakima wild and hatchery fish were smallest. Upper Yakima hatchery fish were significantly smaller than all the other populations ($p \leq 0.02$; Tukey multiple-comparisons test). Age-5 females followed this same trend with American the largest, followed by Naches, and upper Yakima wild and hatchery. Upper Yakima hatchery fish were significantly smaller than all the other populations.

**Run/Spawn Timing**

RAMF Passage Timing

Hatchery and wild fish passage timing at RAMF was very similar in 2003. Median passage timing of hatchery and wild adult fish at RAMF differed by 1 day with hatchery fish passing earlier (Fig. 5). The two group's passage timing distributions were not significantly different in a K-S test ($p$=0.561). Jacks were significantly later than adults in their movement past RAMF, lagging by 20 to 21 days in median passage date compared to adults (Fig. 5).

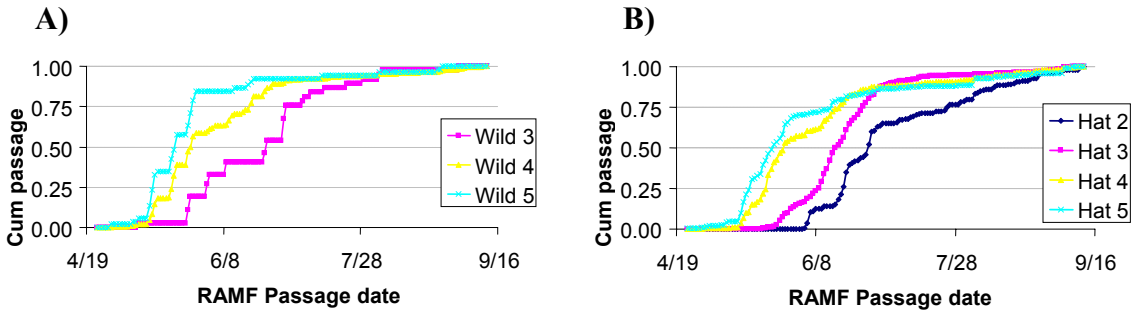



**Figure 5. Cumulative run passage at RAMF during 2003 by A) Wild and B) Hatchery age classes.**

When passage timing is broken down into individual age classes (sexes pooled) the trends observed in 2002 were repeated. Age-5's passed earliest (median date May 22-23), followed 4-5 days later by age-4's (median date May 26-28), age-3's (median date June 14-15) and finally age-2's (median date June 27; Fig. 5B).

OCT vs SNT

We compared OCT and SNT treatment groups' passage timing at RAMF for age-2, -3, -4 and –5 fish using K-W ANOVA and found no significant treatment effect on passage timing ($p \geq 0.064$) within any age class. OCT and SNT median RAMF dates within age classes differed by no more than 3 days.

Relationship of CESRF Spawning Date to RAMF Passage Timing

Males and hatchery females demonstrated no significant linear relationship between passage date at RAMF and date of spawning at CESRF in 2003 ($p \geq 0.21$; Fig. 6). Wild females did show a significant positive relationship ($p$=0.010, n=201), however it explained only 3% of the total variation in spawn timing. These results are essentially the same as those observed in 2001 and 2002 showing little to no relationship between passage timing at RAMF and date of spawning. The lower (earlier) position of the hatchery trend lines in Figure 7 highlights the earlier spawn timing of male and female hatchery fish at CESRF.

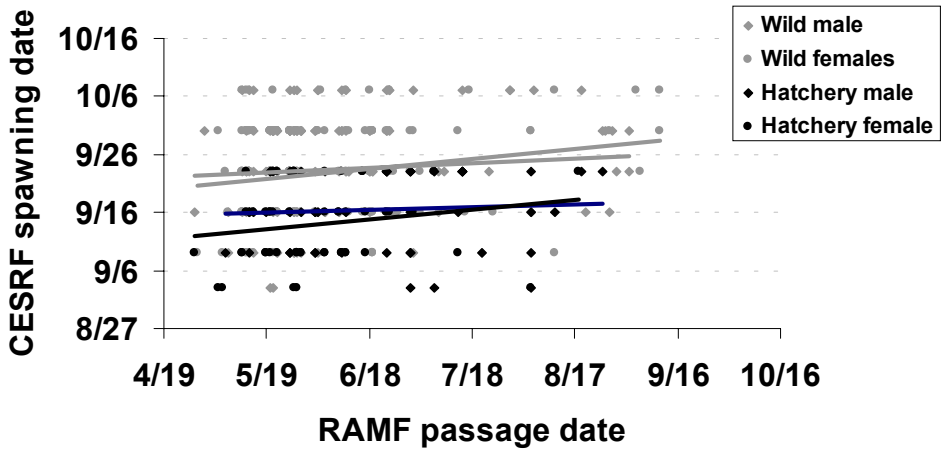



**Figure 6. Linear relationship between passage date at Roza Adult Monitoring Facility (RAMF) and date fish were spawned at CESRF for hatchery (black) and wild (gray) origin females (circles) and males (diamonds).**

Spawn Timing

There has been a distinct shift in spawn timing between hatchery and wild origin fish held at CESRF with hatchery fish maturing 6 days earlier than wild fish based on the dates fish matured and were spawned in 2003. This is shown by the earlier (lower placement) of the hatchery regression lines in Figure 6. A 2-way ANOVA of spawn timing found a significant Origin effect ($p$<0.001), but no significant Sex or Sex*Origin interaction effects (Table 13).

Table 13. Two-way ANOVA results comparing spawn timing at CESRF for Sex (Male/Female), Origin (Hatchery/Wild) and interaction effects.

| Source | ssq | df | MS | F-ratio | $p$-value |
|---|---|---|---|---|---|
| Sex | 214.4 | 1 | 214.4 | 3.8 | 0.053 |
| Origin | 3399.7 | 1 | 3399.7 | 59.5 | <0.001 |
| Sex*Origin | 72.0 | 1 | 72.0 | 1.3 | 0.262 |
| Error | 28900.3 | 506 | 57.1 | | |

Mean and median spawn timing of wild populations based on carcass recoveries were August 15 and 18, respectively, for the American River (n=233) and September 13 and 14, respectively, for the Naches (n=163) population. The between-population difference in spawn timing of 27-29 days was significant in a K-W test ($p<0.001$). Mean spawn timing of upper Yakima River hatchery and wild fish based on in-river carcass recoveries was not estimated for 2003 due primarily to the short 11 day time period during which carcasses were recovered in-river.

**Carcass Recovery Bias**

Relationship between RAMF and Carcass recoveries

The proportions of hatchery and wild origin jacks passed upstream at RAMF were 50 and 49%, respectively (Table 2), in 2003 while hatchery and wild origin jacks made up 39 and 49% of the carcasses recovered, respectively (Table 4). In general, these recovery rates for small males are much higher than observed in past years. However, the proportion of hatchery jacks recovered was significantly lower than expected based on the RAMF results, while the wild proportion was not.

The F:M ratio of adult hatchery origin fish (excluding jacks) was 1.5 in the CESRF sample (n=114) and 2.6 in the carcass recover sample (n=247). As in 2001 and 2002, females represented a significantly larger proportion of the hatchery origin carcass sample ($X^2$=18.19 with Yates correction; $p<0.001$), demonstrating that female carcasses were recovered at higher rates than male carcasses. This was not true of the wild carcass samples, however, which did not differ significantly from the RAMF sample.

Within age classes, the mean POHP of carcass recoveries did not differ significantly from fish sampled at RAMF (Table 14; Type effect $p\geq0.312$). Thus, carcass recovery length distributions accurately represented size-at-age.

Table 14. Two-way ANOVA results comparing log(POHP lengths) of age-3, -4 and -5 upper Yakima hatchery and wild populations for Age (3/4/5) and Type (Carcass/CESRF) and interaction effects.

| | Source | ssq | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|---|
| Hatchery | Age | 1.950 | 2 | 0.975 | 863.363 | <.001 |
| | Type | 0.001 | 1 | 0.001 | 1.026 | 0.312 |
| | Age*Type | 0.003 | 2 | 0.001 | 1.281 | 0.279 |
| | Error | 0.559 | 495 | 0.001 | | |
| Wild | Age | 0.766 | 2 | 0.383 | 334.369 | <.001 |
| | Type | <0.001 | 1 | <0.001 | 0.357 | 0.550 |
| | Age*Type | 0.005 | 2 | 0.002 | 2.062 | 0.129 |
| | Error | 0.441 | 385 | 0.001 | | |

# Discussion

## Age Composition

The strong 1998 cohort of hatchery origin had an effect on 2003 returns, increasing the age-5 component of hatchery fish to 24% from the more typical 4-8%. Wild fish did not experience this same strong 1998 cohort. In addition, the very strong 2000 cohort returning as age-3's, made up almost 50% of both the hatchery and wild run and heavily effected the sex ratio and size of males on the spawning grounds. Thus, the 2003 return's age composition was not typical.

## Size-at-Age

The smaller size-at-age of hatchery fish has consistently been observed since the first adult returns in 2001. These differences have shown up every year in the age-3's and the magnitude of the POHP length differences are often similar between age-3 and -4's. Thus, the effects of whatever is causing the growth rate difference must be occurring primarily during the 14-17 months after release and prior to age-3's returning and passing RAMF. There are four distinct areas fish pass through during this period: the Yakima/Columbia River during downstream smolt migration, the Columbia River estuary and near shore ocean environment during the rapid growth phase, and the Columbia River during the return migration. The extremely large PIT tagged smolts released over the past 5 years by the YKFP offers the potential to study closely the smolt outmigration period. The YKFP has not begun to fully exploit this database yet in order to investigate differences in outmigration timing and growth differences between upper Yakima River hatchery and wild smolts.

## Run/Spawn Timing

Hatchery fish matured earlier in 2003 than wild fish by 6 days. Our metric for maturation timing, spawning date at CESRF, is rather crude since spawning only occurs once each week. However, even with this coarse measurement we are seeing a shift in timing of maturation (see Fig. 6). The actual "effective" or realized difference in spawn timing of broodstock was 8, rather than 6 days. This is because we included the spawning channel fish in our comparisons above. Channel fish were all selected on a single day, September 23, after the mean spawning date for hatchery fish resulting in a later hatchery mean spawning date. Removing the spawning channel fish from the analysis results in an 8 day difference in maturation timing. Another example of this kind of inadvertent selection on spawn timing occurred in 2001. Nearly 50% of the females that year were found to have high levels of BKD and after spawning, their gametes were removed from production. The unfortunate part of this is that practically all of the high BKD titer females came from the last half of the run, effectively selecting for much earlier spawn timing. The full expression of this selection on female maturation timing will be expressed in age-4 females returning in 2005.

We observed no significant differences between hatchery and wild fish passing RAMF in 2003 with median passage dates separated by approximately 1 day. There were however, significant age effects on passage timing at RAMF. The older fish passed upstream earlier and presumably had access to the spawning grounds earlier, as well. Adult median passage was 20-21 days earlier than jacks. We did not find any evidence of protandry, earlier passage of males than females (Morbey and Ydenberg 2001), in adult fish with male median passage date actually being 1.5 days later than females.

We were not able to compare temporal differences in hatchery and wild carcass recoveries in 2003 because of the change in carcass recovery methodology, but the major trends in spawn timing were similar to previous years with large differences between upper Yakima River, American River, and Naches populations in temporal distribution of carcass recoveries. This has been noted by others, as well (Major and Meghell 1969; Fast et al. 1991; Knudsen et al. 2002). The American River was once again the earliest spawning group, followed by the Naches and finally the upper Yakima River. Fry emergence is often synchronized across populations within a river system occurring during the optimum spring period maximizing survival (Brannon 1987). American and upper Yakima River fry emergence timing does appear to be synchronized (Fast et al. 1991). The populations with the coldest water temperatures spawn first so that the eggs' total temperature unit accumulations, which determine fry emergence timing, will be equivalent across populations at emergence. Thus, temporal differences in spawning are driven by water temperatures during egg incubation, which are coldest in highest elevation American River, followed by the Naches, and warmest in the lower elevation upper Yakima. In addition, since upper Yakima River fish spawn over a month later on average than American River fish, they must have the energy reserves to maintain themselves over an additional month of holding, when mean water temperatures are warmer and daily metabolic costs are higher. Because of this, we hypothesize that upper Yakima fish should invest more into somatic growth that can be quickly and efficiently metabolized (i.e. visceral fat stores) and devote relatively less growth into muscle mass, which is less efficiently converted back to energy, than American River fish. This would also tend to produce larger fish at age in the American River population.

**Carcass Recovery Bias**

In 2003 there was a significant change in the methods used to recover carcasses in the upper Yakima River. In previous years YN personnel had combined the tasks of redd monitoring and carcass recovery, and both tasks were done on a weekly basis over the length of the upper Yakima River from the time redds were first observed until no new redds were seen. Between 1990 and 2002 this averaged 36 days between the first and last observations (range 24 to 55 days). In 2003 the carcass recovery work was conducted by NMFS personnel (A. Dittman, NMFS, pers. comm..). The temporal period sampled was shortened significantly to just 11 days during and just after peak spawning had occurred and the number of people involved was increased. The number of carcasses recovered also increased from 62 to 326 collected between 1997-2001 to 655 carcasses in 2003. The decreased temporal period sampled, increased daily effort, and likely higher CPUE due to the ability to focus on only carcass recovery, caused significant differences

between the 2003 recoveries and previous years. However, we have no controlled comparison to make a quantitative assessment of the within-year differences in the two methods. We can compare across years and there are some important differences. Beginning in 2001 we have compared the age and sex composition and size-at-age of fish sampled passing RAMF (an unbiased sample) to those collected as carcasses from the spawning grounds. In each of those years we observed that female carcasses were recovered at significantly higher rates than males and that older, larger fish were recovered at higher rates than smaller, younger fish (Knudsen et al. 2002; Knudsen et al. 2003). These historical carcass samples had F:M ratios of 3 or greater; about twice the RAMF F:M ratio. In 2003 the RAMF and carcass samples were more similar with F:M ratios ranging from 1.5 to 2.6, exhibiting less of the sex bias observed in previous years, but still demonstrating a significantly higher proportion of hatchery females and fewer hatchery jacks than observed at RAMF.

## Conclusions

The persistent observation of differences in size-at-age after only a single generation of domestication over the past three return years (2001 to 2003) are both statistically and biologically significant. Irrespective of the underlying causes, a significant shift in body size from the locally adapted optimum will reduce the productivity and fitness of naturally spawning hatchery fish through counter selection pressures against the smallest hatchery fish. The positive side to counter selection, if there can be one, is that if the effected traits are heritable, then disproportionately reducing the fitness of those furthest from the trait's optimum will reduce the magnitude of the selection response in the next generation. This will blunt the impacts on future generations, but at the cost of productivity in the current generation. In addition, other traits such as fecundity which are correlated with body size have also been shifted away from their locally adapted optima, and counter selection in the wild acting on these traits will result in additional reductions in fitness and productivity driving those trait distributions back toward their locally adapted optimum over time (Lande and Arnold 1983; Law 1991; Taylor 1991). The magnitude of the one-generation response in POHP length distribution represents a response of approximately 0.5 standard deviation·generation$^{-1}$ or 0.5 haldane (Haldane 1949) in age-3 and -4 fish. Size-at-age is a heritable trait influenced by both natural and sexual selection pressures (Schroder 1981; Blair et al. 1993; Quinn and Foote 1994; Fleming and Petersson 2001; Hendry 2001), and responds to artificial selection (Gjerde and Gjerdem 1984; Su et al. 2002), so the potential for a genetic response is likely. However, size-at-age is also subject to environmentally driven phenotypic plasticity (Riddell 1986; Hard 1995). Identifying the mechanism(s) or cause(s) of the reduction in size-at-age is critical to understanding supplementation's impacts on fitness in subsequent generations. There is little argument that natural productivity of the current generation of spawners will be reduced. A study to monitor and estimate the affects of domestication on supplementation in the YKFP was begun in 2002 (Busack et al. 2002). This effort will be crucial to helping us understand and identify the genetic component to the observed differences in traits, such as size-at-age.

We continued to document significant between population trait variation in the three Yakima River basin wild spring chinook populations, including size-at-age, age composition, sex ratios, sexual dimorphism, and spawn timing. These differences likely reflect local adaptations by each population to their unique set of selection pressures and help us put a context to the changes observed in the hatchery origin returns.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

## Acknowledgements

We wish to thank the Yakama Nation Roza Adult Monitoring Facility crew and Yakama Nation spawner survey personnel. Without their efforts and the data they collected in support of the YKFP's Monitoring and Evaluation effort, a significant portion of the work presented above would not have been possible. Andy Dittman, NMFS, kindly provided the upper Yakima River carcass recovery data from 2003. In addition, we would like to thank Dana Andersen, Valerie Vanderwall, and Lang Ngyuen (WDFW) and the Cle Elum Research and Supplementation Facility personnel (YN) involved in sampling and spawning broodstock at CESRF. Bill Bosch (YN) provided valuable help in data management, coordination, and access. Finally, we thank Bonneville Power Administration (BPA) for providing funding and David Byrnes (BPA) whose help in securing and administering funding for this work was greatly appreciated.

## References

Beacham, T.D., and C.B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). J. Fish Biol. 42:485-508.

Beer, W.N., and J.J. Anderson. 2001. Effect of spawning day and temperature on salmon emergence: interpretations of a growth model for Methow River chinook. Can. J. Fish. Aquat. Sci. 58:943-949.

Berejikian, B.A., E.P. Tezak, S.L. Schroder, C.M. Knudsen, and J.J. Hard. 1997. Reproductive behavioral interactions between captively-reared and wild coho salmon *(Oncorhynchus kisutch*). ICES Journal of Marine Science 54(6): 1040-1051.

Bilby, R. E., Fransen, B. R., and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Can. J. Fish. Aquat. Sci. 53:164-173.

Blair, G.R., D.E. Rogers, and T.P. Quinn. 1993. Variation in life history characteristics and morphology of sockeye salmon in the Kvichak, River system, Bristol Bay, Alaska. Trans. Am. Fish. Soc. 122:550-559.

BMDP. 1992. BMDP Statistical software Release 7.0. W.J. Dixon, editor. University of California Press, Los Angles.

Bilton, T.H. 1980. Returns of adult coho salmon in relation to mean size and time at release of juveniles to the catch and the escapement. Can. Tech. Report of Fish. Aquat. Sci. No. 941.

Boechler, J., and S. Jacob. 1987. Catch and escapement of fall chinook salmon from the Salmon River, Oregon, 1986. Oreg. Dept. Fish Wildl., Fish Div. Prog. 60 p.

Bosch, B. 2004. Broodstock needs. Memo to YKFP Monitoring Implementation and Planning Team.

Brannon, E. 1987. Mechanisms stabilizing salmonid fry emergence timing. Can. Spec. Publ. Aquat. Sci. 96:120-124.

Bumgarner, J., G. Mendel, L. Ross, D. Milks, J. Dedloff, and M. Varney. 1994. Lower Snake River Compensation Plan Tucannon River Spring Chinook Hatchery Evaluation Program 1996 Annual Report to USFWS. Washington Dept. Fish and Wildlife.

Busack, C., and A. Marshall. 1991. Genetic analysis of YFP chinook salmon stocks. Pages 2-45 *in* Busack, C., C. Knudsen, A. Marshall, S. Phelps, and D. Seiler. Yakima hatchery experimental design. Progress report to Bonneville Power Administration, Contract DE-B179-89BP00102.

Busack, C., C. Knudsen, D. Seiler, B. Hopley, A. Marshall, and S. Phelps. 1992. Yakima hatchery experimental design. Semi-annual progress report to Bonneville Power Administration, Project 89-082, Contract DE-B179-89BP00102.

Busack, C., B. Watson, T. Pearsons, C. Knudsen, S. Phelps and M. Johnston. 1997. Spring Chinook Supplementation Monitoring Plan. Report to Bonneville Power Administration, Publ. No. DOE/BP 64878-1. 185 pp.

Busack, C., S. Schroder, and C. Knudsen. 2002. YKFP Spring Chinook Domestication/Monitoring Designs. Pages 10-28 in *Yakima/Klickitat Fisheries Project Genetic Studie*s. BPA Annual Report 2001.

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transaction of the American Fisheries Society 115:726-735.

Clutter, R. I. and L.E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission, Bulletin 9.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. Vol. 38 of CBMS-NSF Regional Conference Series in Applied Mathematics. Philadelphia, Penn.: SIAM.

Fast, D., J. Hubble, M. Kohn and B. Watson. 1991. Yakima River spring chinook enhancement study. Final Report, BPA. May 31, 1991

Fisher, R.A. 1936. The use of multiple measurements in taxonomic problems. Annals of Eugenics 7:179-188.

Fleming, I.A. 1998. Pattern and variability in the breeding system of Atlantic salmon (*Salmo salar*), with comparisons to other salmonids. Can. J. Fish. Aquat. Sci. 55(suppl. 1):59-76.

Fleming, I.A., and M. R. Gross. 1990. Latitudinal clines: A trade-off between egg number and size in Pacific salmon. Ecology 71: 1-11.

Fleming, I.A., and M.R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. Aquaculture 103:101-121.

Fleming, I.A., and M.R. Gross. 1993. Breeding success of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. Ecological Applications 3:167-185.

Foote, C.J. 1990. An experimental comparison of male and female spawning territoriality in a Pacific salmon. Behavior 115:283-314.

Fresh, K.L., S.L. Schroder, E.C. Volk, J. Grimm, and M. Mizell. In preparation. Evaluation of the Cedar River Sockeye salmon hatchery: Analyses of adult otolith recoveries. Report to Washington Department of Fish and Wildlife.

Gallinat, M., J. Bumgarner, L. Ross, and M. Varney. 2001. Tucannon River spring chinook salmon hatchery evaluation Program, 2000 Annual Report No. FPA01-05. 44 pp.

Gjerde, B. and T. Gjerdem. 1984. Estimates of phenotypic and genetic parameters for carcass traits in Atlantic salmon and rainbow trout. Aquaculture 80: 25-44.

Haldane, J. 1949. Suggestions as to quantitative measurement of rates of evolution. Evolution 3:51-56.

Hamon, T, C. Foote, R. Hilborn and D. Rogers. 2000. Selection on morphology of spawning wild sockeye salmon by a gill-net fishery. Transactions of the American Fisheries Society 129: 1300-1315.

Hard, J. 1995. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. Amer. Fish. Soc. Sym. 15:212-225.

Hard, J., B. Berejikian, E. Tezak, S. Schroder, C. Knudsen, and L. Parker. 2000. Evidence for morphometric differentiation of wild and captively reared adult coho salmon: a geometric analysis. Environ. Bio. Fish. 58: 61-73.

Hendry, A. 2001. Adaptive divergence and the evolution of reproductive isolation in the wild: an empirical demonstration using introduced sockeye salmon. Genetica 112-113:515-534.

Hendry, A.P., and T.P. Quinn. 1997. Variation in adult life history and morphology among Lake Washington sockeye salmon (*Oncorhynchus nerka*) populations in relation to habitat features and ancestral affinities. Can. J. Fish. Aquat. Sci. 54:75-84.

Hendry, A.P., J.E.Hensleigh, and R.R. Reisenbichler. 1998. Incubation temperature, developmental biology, and the divergence of sockeye salmon (*Oncorhynchus nerka*) within Lake Washington. Can. J. Fish. Aquat. Sci. 55:1387-1394.

Hendry, A.P., A.H. Dittman, and R.W. Hardy. 2000. Proximate composition, reproductive development and a test for trade-offs in captive sockeye salmon. Trans. Am. Fish. Soc. 129:1082-1095.

Hockersmith, E., J. Vella, L. Stuehrenberg, R. Iwamoto, and G. Swan. 1994. Yakima River radio-telemetry study: Spring chinook salmon, 1991-1992. Annual Report 1991-1992. DOE/BP-00276-1. Bonneville Power Administration, Portland, OR.

Johnston, M., and S. McCutcheon. In preparation. Monitoring chinook salmon broodstock using 18 mm PIT tags implanted in the pelvic muscle.

Kassler, T.W., A. Frye and J. Von Bargen. 2004. DNA-Based Gender Determination of Hatchery-Origin Chinook Salmon Passing Roza Dam (Yakima River) in 2002 and 2003.

Kinnison, M., M. Unwin, A. Hendry, and T. Quinn. 2001. Migratory costs and the evolution of egg size and number allocation in new and indigenous salmon populations. Evolution 55:1656-1667.

Knapp, R., and V. Vrendenburg 1996. Spawning by California golden trout: Characteristics of spawning fish, seasonal and daily timing, redd characteristics and microhabitat preferences. Trans. Am. Fish. Soc. 125:519-531.

Knudsen, C.M. 1992. Spawning ground recovery bias: Preliminary 1991 Marion Drain Fall chinook results. Memo to C. Smith, WDF, dated May 14, 1992.

Knudsen, C.M. 1991. Scale pattern and age/length analysis of Yakima River spring chinook. *In* Busack, C., C. Knudsen, A. Marshall, S. Phelps and D. Seiler. Yakima hatchery experimental design. Progress Report, DOE/BP-00102.

Bonneville Power Administration, Portland, OR.

Knudsen, C., S. Phelps, C. Busack and D. Seiler. In preparation. Effects of size selective gillnet fisheries on coho salmon (*Oncorhynchus kisutch*): Temporal trends in size-at–maturity and fecundity.

Knudsen, C., S. Schroder, J. Rau, C. Strom, and M. Hammlin. 2002. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild spring chinook: Gametic and juvenile traits. Pages 41-61 in *Reproductive Ecology of Yakima River hatchery and wild spring chinook and Juvenile-to-Adult PIT Tag Retention Study*, ed. by C. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2001.

Knudsen, C.M., S.L. Schroder, T. Pearsons, J. A Rau, A. L. Fritts, and Strom, C.R. 2003. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild Spring chinook: Gametic and juvenile traits. Pages 37-62 in *Reproductive Ecology of Yakima River hatchery and wild spring chinook*, ed. by C. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2002.

Lande, R., and S.J. Arnold. 1983. The measurement of selection on correlated characters. Evolution 37(6):1210-1226.

Larsen, D. A., B. R. Beckman, K. A. Cooper, D. Barrett, M. Johnston, P. Swanson, and W. W. Dickhoff. 2004. Assessment of high rates of precocious male maturation in a spring chinook salmon supplementation hatchery program. Transactions of the American Fisheries Society 133:98-120.

Law, R. 1991. On the quantitative genetics of correlated characters under directional selection in age-structured populations. Phil. Trans. R. Soc. Lond. B. 331: 213-223.

Leider, S.A., P. Hulett, J.J. Loch, and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the adult return stage. Aquaculture 88:239-252.

Lynch, M., and M. O'Hely. 2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics 2**:** 363–378.

Major, R.L. and J.L. Mighell. 1969. Egg to migrant survival of spring chinook (*Oncorhynchus tshawytscha*) in the Yakima River, Washington. Washington Fishery Bulletin 67(2):347-359.

Morbey, Y. E. , and R.C. Ydenberg. 2001. Protandrous arrival timing to breeding areas: a review. Ecology Letters 4:663-673.

Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Schuett-Hames, and T. P. Quinn. 1996. Stream-bed scour, egg burial depths, and the influence of salmonid

spawning on bed surface mobility and embryo survival. Can. J. Fish. Aquat. Sci.53: 1061 - 1070

Nunney, L. 1991. The influence of age structure and fecundity on effective population size. Proc. R. Soc. Lond. B 246:71-76.

Peterson, A. 1954. The selectivity of gill nets of Fraser River sockeye salmon. International Pacific Salmon Fisheries Commission Bulletin No. 5.

Pianka, E. 1976. Natural selection of reproductive tactics. Amer. Zool. 16:775-784.

Resenbichler, R., and J. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, (*Salmo garidneri*), Journal of the Fisheries Research Board of Canada 34:123-128.

Rogers, D. 1987. The regulation of age at maturity of Wood River sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. No. 96:78-89.

Quinn, T., and C.J. Foote. 1994. The effects of body size and sexual dimorphism on the reproductive behavior of sockeye salmon, *Oncorhynchus nerka* . Animal Behavior 48:751-761.

Quinn, T., A.P. Henry, and L.A. Wetzel. 1995. The influence of life history trade-offs and the size of incubation gravels on egg variation in sockeye salmon (*Oncorhynchus nerka*). Oikos 74:425-438.

Quinn, T., J. Peterson, V. Gallucci, W. Hershberger, and E. Brannon. 2002. Artificial selection and environmental change: countervailing factors affecting the timing of spawning by coho and chinook salmon. Trans. Am. Fish. Soc. 131:591-598.

Riddell, B.E. 1986. Assessment of selective fishing on age at maturation in Atlantic salmon (*Salmo salar*): A genetic perspective, p. 102-109. *In* D.J. Meerburg [ed.] Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Roff, D. 1988. The evolution of migration and some life history parameters in marine fishes. Envoron. Biol. Fishes 22:133-146.

Sampson, M., and D. Fast. 2001. Monitoring And Evaluation. Yakima/Klickitat Fisheries Project Final Report 2000. BPA Report DOE/BP-00000650-1.

Schroder, S.L. 1981. The role of sexual selection in determining overall mating patterns and mate choice in chum salmon. PhD Thesis, University of Washington, Seattle, WA.

Schroder, S.L. 1982. The influence of intrasexual competition on the distribution of chum salmon in an experimental stream. *In*: Salmon and Trout Migratory Behavior Symposium (*Ed*. E.L. Brannon and E.O. Salo), pp. 265-285. Seattle: School of

Fisheries, University of Washington.

Schroder, S.L., C.M. Knudsen, B. Watson, T. Pearsons, S. Young, and J. Rau. 2002. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2001 Annual Report.

SPSS. 1998. SYSTAT 8.0 Statistics, SPSS, Inc. Chicago, IL

Smoker, W., A. Gharrett, and M. Stekoll. 1998. Genetic variation of return date in a population of pink salmon: a consequence of fluctuating environment and dispersive selection? Alaska Fishery Research Bulletin 5:46-54.

Stearns, S.C. 1989. The evolutionary significance of phenotypic plasticity. BioScience 39:436-445.

Steen, R.P., and T.P. Quinn. 1999. Egg burial depth by sockeye salmon (*Oncorhynchus nerka*): implications for survival of embryos and natural selection on female body size. Can. J. Zool. 77:836-841.

Su, G., L. Liljedahl, and G. Gall. 2002. Genetic correlations between body weight at different ages and reproductive traits in rainbow trout. Aquaculture 213:85-94.

Taylor, E. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

Unwin, M.J. and G.J. Glova. 1997. Changes in life history parameters in a naturally spawning population of chinook salmon (*Oncorhynchus tshawytscha*) associated with releases of hatchery-reared fish. Can. J. Fish. Aquat. Sci. 54(6): 1235-1245.

van den Berghe, E.P., and M.R. Gross. 1984. Female size and nest depth in coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 41:204-206.

van den Berghe, E.P., and M.R. Gross. 1989. Natural selection resulting from female breeding competition in a Pacific salmon (Coho: *Oncorhynchus kisutch*). Evolution 43:125-140.

Ward, F. J. 1959. Character of the migration of pink salmon to the Fraser River spawning grounds. International Pacific Salmon Fisheries Commission Bulletin No. 10.

Zar, J. 1984. Biostatistical analysis. Second edition. Prentice-Hall, Inc.

Zhou, S. 2002. Size-dependent recovery of chinook salmon in carcass surveys. Trans. Am. Fish. Soc. 131(6):1194-1202.

# Chapter 2

# Monitoring Phenotypic and Demographic Traits of upper Yakima River Hatchery and Wild Spring Chinook: Gametic and Juvenile Traits

Prepared by:

Curtis M. Knudsen[1], Steve L. Schroder[2], Todd N. Pearsons[3], Jason A. Rau[4], Anthony L. Fritts[3], Jennifer L. Scott[3] and Charles R. Strom[4]

[1] Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

[2] Washington Department of Fish and Wildlife, 600 Capitol Way North Olympia, WA 98501-1091

[3] Washington Department of Fish and Wildlife, 201 N. Pearl Street Ellensburg, WA 98926

[4] Yakama Nation, Cle Elum Research and Supplementation Facility Cle Elum, WA 98922

# Abstract

As part of the Reproductive Ecology and Domestication Monitoring and Evaluation program in the Yakima/Klickitat Fishery Project (YKFP), we compared upper Yakima River hatchery and wild origin spring chinook returns in 2003 over an array of fitness related traits characterizing each group's gametes and progeny ("button up" stage fry).

**Fecundity and Fecundity/Female Size Relationship**

Age-4 hatchery females (3,907 eggs) were significantly less fecund than wild origin females (4,349 eggs) on average. Age-5 wild (5,427 eggs) and hatchery (5,732 eggs) origin females were not significantly different from each other, but were significantly more fecund than age-4 females.

Fecundity and female body size showed significant strong, positive correlations in both hatchery and wild origin females. The fecundity/length and fecundity/weight slopes of hatchery and wild origin females were not significantly different. Age-5 females had stronger, positive correlations between female body size and fecundity than in previous years. Including body weight, mean egg weight and POHP in multi-variate fecundity regression equations significantly increased the amount of variation explained and improved the precision of estimation equations using just female body size.

**Egg Weight**

There was no significant difference between mean egg weights of age-4 hatchery (0.184 g) and wild (0.188 g) or age-5 hatchery (0.200 g) and wild (0.208 g) origin females. Age-4 eggs were significantly lighter than age-5 eggs by approximately 10%. These were similar to the results for 2001 and 2002 returns. There were weak positive correlations between egg weight and female POHP and body weight. The relationship between egg weight and fecundity was negative and significant only in wild females.

**Gamete Weight and Reproductive Effort**

Reflecting the results for fecundity, gamete weight was significantly greater for wild age-4 females (mean= 812 *g*) compared to age-4 hatchery females (mean= 732 *g*). Age-5 hatchery females (mean= 1150 *g*) had greater mean gamete weight than wild age-5 females (mean= 1115 *g*), but the difference was not significant.

Female Reproductive Effort (RE), the ratio of the weight of gametes to total body weight, did not differ significantly between age-4 or 5 females regardless of origin in 2003 (age-4 hatchery mean=0.190; wild females mean=0.197; age-5 wild mean=0.190; hatchery mean=0.193). This mirrors results found in 2001 and 2002.

**Egg-to-Fry Survival and Developmental Abnormalities**

There was no significant difference in egg-to-fry viability of hatchery (median viability =92.5%) and wild (median viability =92.1%) origin females. Both hatchery (median=0.2%) and wild (median=0.4%) origin fish had low percentages of abnormally developing fry with no significant difference between groups. These results are consistent with those from 2001 and 2002.

**Fry Size**

Wild fry (34.8 *mm*, 0.31 *g*, and 1.38 KD) were not significantly different in size from hatchery fry (34.7 *mm*, 0.31 *g* and 1.38 KD). There were strong positive relationships between fry size and egg weight for both wild and hatchery origin females. ANCOVA indicated that hatchery and wild fry slopes were not significantly different. As in 2001 and 2002, there were either no or weak positive female body size/fry size relationships, explaining at most 15% of the total variation in fry size.

**Fry Emergence Timing**

This research effort was initiated in 2002 and repeated in 2003 at CESRF. Approximately 100 eyed eggs from individual females were placed into incubation substrate within a covered Incubation Chamber (IC) through which water was continuously upwelling. After hatching, fry were allowed to volitionally emerge from the substrate and exit from the IC's into a collection vessel. Each year eggs from 16 hatchery and 16 wild origin females were placed into the IC's and emerging fry were enumerated daily and sampled for weight and length. In 2002, median emergence timing and the range of emergence timing were not significantly different between hatchery and wild fry. In 2003, there was a significant difference, wild origin median emergence was 3 days later than hatchery and the wild range was 4 days shorter.

**Male Testes/Body Size Relationships**

The testes of sexually mature hatchery and wild origin males were extracted and examined in relation to size, age and origin. Wild and Hatchery origin age-3 males did not exhibit significant differences in either mean testes weight, log(testes weight)/log(body size) relationships, or Reproductive Effort (RE). Testes weight was positively correlated with body size across all ages. Age-2, -3 and -4 males each had significantly different mean testes weights. Age-2 males had a mean RE of 13%, which was significantly higher than in age-3 (6%) and -4 (6%) males. Thus, age-2 males allocated approximately twice the proportion of their total body weight toward gamete production than older males. This is an adaptation to compensate for their inordinate size disadvantage relative to older anadromous males during spawning.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

# Introduction

A critical aspect of assessing success in the Yakima/Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program is evaluating traits that determine natural production and to compare hatchery and wild origin fish across these traits. Significant changes in locally adapted traits due to hatchery influence, whether of genetic or environmental origin, will likely be maladaptive, resulting in reduced population productivity and fitness (Taylor 1993; Hard 1995) and project success is defined as increasing natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack *et al*. 1997). Naturally spawning hatchery fish have been shown to be less reproductively successful then wild fish (Reisenbichler and McIntyre 1977; Chilcote *et al*. 1986; Leider *et al*. 1990; Blouin 2003), including upper Yakima River spring chinook (Schroder *et al*. 2003). This is particularly true of populations that have experienced multiple years of domestication (reviewed in Schroder *et al*. 2002 and Blouin 2003). Traits such as fecundity (Healey and Heard 1985; Fleming and Gross 1990; Beacham and Murray 1993), emergent fry size and fry energy reserves (Thorpe *et al*. 1984; Hendry *et al*. 2001), egg incubation rates, and emergence timing (Beacham and Murray 1993; Quinn *et al*. 1995) affect reproductive success and fitness and reflect local adaptations (Taylor 1991; Hendry *et al*. 1998; Quinn *et al*. 2001). Other traits, such as the body size and number of eggs produced per unit body size or the biomass of gametes per unit body size, indicate how populations have responded to local selection forces optimizing allocation of energy between somatic growth, gametes, migration, competition and mating (Heath *et al*. 1999; Kinnison *et al*. 1998; Kinnison *et al*. 2001; Heath *et al*. 2003).

In this chapter, we make comparisons between hatchery origin fish from the Cle Elum Supplementation Research Facility (CESRF) and upper Yakima River wild origin spring chinook returning in 2003 over a suite of traits affecting fitness and reproductive success. These include fecundity, female body size/fecundity relationships, female reproductive effort, egg size (weight), egg-to-fry viability, fry size, fry length/egg size relationships, female size/fry size relationships, and occurrences of developmental abnormalities. We describe work begun in 2002 and continued in 2003, designed to compare traits of emerging fry. And we examine the allocation of energy into gametes and body mass by males of hatchery and wild origin. Many of these traits have been measured on wild origin upper Yakima fish annually beginning with the first broodstock collection in 1997 and on hatchery returns beginning with the first adult returns in 2001. In this report we will focus primarily on 2003 returns, but in some cases will compare results, at least qualitatively, across earlier years.

Tracking fitness related traits over time is also an important aspect of monitoring domestication effects to determine whether divergence in heritable traits is occurring between the supplemented naturally spawning population, a hatchery control line established in 2002, and a yet to be established wild Naches basin control population (see Busack *et al*. 2004). Thus, we will be expanding our comparisons to the wild origin Naches population in future reports.

# Methods and Materials

Study Populations

The upper Yakima River is a tributary to the Yakima River, which discharges into the Columbia River (Fig. 1). Monitoring of the wild upper Yakima River population has occurred annually at Roza Adult Monitoring Facility (RAMF) since wild origin broodstock collection first began in 1997. The first hatchery reared cohort began returning in 2000 as anadromous age-3 jacks, 2001 as age-4 adults, and age-5 adults in 2002. However, sexually mature non-anadromous age-2 hatchery origin males have been observed on active redds within 5 months after their release beginning in 1999 (Pearsons *et al*. 2003). In addition, wild and hatchery origin precocious males have been video taped and observed spawning with adult pairs in the upper Yakima River (Knudsen and Schroder, pers. communication) and have successfully produced offspring in competition with naturally spawning adult males (Schroder *et al*. 2002; Schroder *et al*. 2003; Schroder *et al*. 2004). Thus, there has had some level of introgression of upper Yakima River hatchery genes beginning in 1999, with the initial release of CESRF smolts, although it is likely to be relatively low based on precocial abundance estimates on the spawning grounds (Busack *et al.* 2004; Pearsons *et al*. 2004).

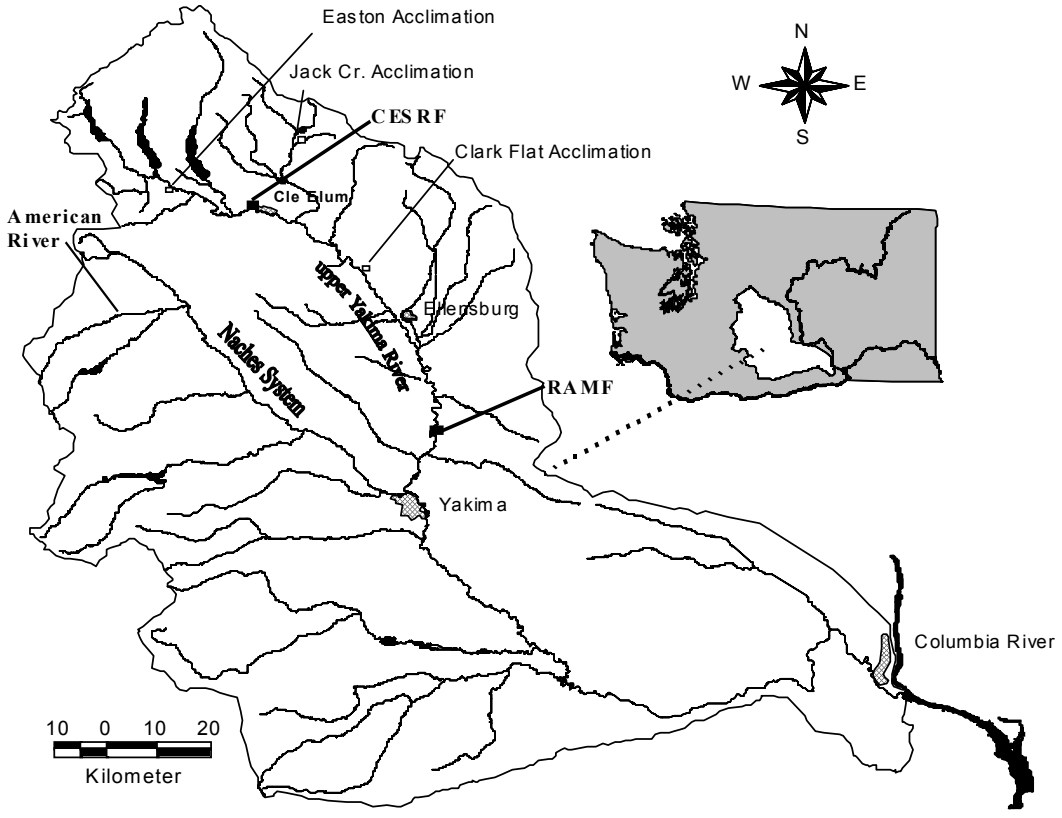



**Figure 1. Yakima River basin showing the upper Yakima River, Roza Adult Monitoring Facility (RAMF), and the Cle Elum Supplementation and Research Facility (CESRF).**

Length, weight, and age data are collected from a subsample of returning spring chinook as they pass upstream through RAMF approximately 1 to 5 months prior to reaching full maturity. For a full description of the sampling, collection, and processing of hatchery and wild origin returns at RAMF during 2003 see Knudsen *et al*. (2004). A subsample of wild and hatchery origin fish are collected from throughout the run and taken to the CESRF. Data collected from wild origin fish selected for broodstock are used to represent the wild population's adult phenotypic and demographic traits, as well as, the following reproductive traits: total gamete mass weight (females), egg weight, female reproductive effort, fecundity, egg-to-fry viability, incidence of abnormally developing fry, fry size, fry emergence timing, and male gamete weight and reproductive effort. In 2003, there were 441 wild origin fish collected for broodstock and reproductive success studies and 143 hatchery origin fish. Of these, 0 age-3, 164 age-4 and 32 age-5 wild origin females and 21 age-4 and 11 age-5 hatchery origin females were sampled for fecundity, reproductive effort, gamete mass, and egg weight.

**Traits**

Total Gamete Mass, Egg Weight, Fecundity and Female Reproductive Effort

Total gamete mass and mean egg weights were collected as females were artificially spawned at CESRF. A large portion of the ovarian fluid was drained off prior to a female's total egg mass being weighed to the nearest 0.1 *g*. A subsample of approximately 30-50 eggs was then collected, weighed to the nearest 0.01 *g*, and the number of eggs in the subsample counted and used to calculate the mean weight of "green" eggs (eggs unexposed to water). A gravimetric estimate of fecundity was then calculated by dividing the total gamete mass by the mean green egg weight. Since it is not possible to drain off all ovarian fluid, gravimetric fecundity estimates are often biased, overestimating fecundity. In order to adjust our estimates of fecundity for this bias we multiplied them by 0.9618, a correction factor developed in 2001 based on hand counts of 19 female egg lots (Knudsen *et al*. 2002b).

The linear relationship between fecundity and female body weight, POHP length and egg size was estimated and comparisons of the slopes of the body size/fecundity regressions were made using ANCOVA. In addition, body weight, POHP length and egg size were examined as predictors of fecundity in a multivariate regression analysis. We compared egg weight distributions of age-4 and -5 hatchery and wild origin females using a 2-way ANOVA (Origin x Age).

Reproductive effort (RE) was calculated for hatchery and wild origin females spawned at CESRF. This metric describes the proportion of a female's total biomass represented by gametes and is calculated by dividing the total egg mass weight (drained of ovarian fluid) by the total body weight including gametes and ovarian fluid. Each year a few females held at CESRF have significant proportions of unripe, overripe, injured, or abnormally developing eggs. We assumed these were primarily due to females being selected for spawning either too early or too late and/or from injuries incurred over the previous 1-5 months during handling, transfer and holding. Egg retention rates in wild

naturally spawning Yakima River spring chinook females are generally very low on the order of 10 or fewer eggs (M. Johnston, YN, personal communication; S. Young, WDFW, unpublished data). Each year while broodstock are being held at CESRF, particularly in the latter weeks of the spawning season, significant numbers of eggs are observed lying on the bottom of the adult holding raceway indicating that some females release gametes prior to artificial spawning. Females with RE values below 0.14 (11 of 244 total hatchery and wild origin females in 2003) were considered to have a significant portion of either under- or over-developed, injured, or lost eggs prior to being spawned and consequently their fecundity, gamete weight, relative fecundity and RE values were excluded from our analyses. An RE value of 0.14 lies over 2 standard deviations from any group's mean. For our purpose - estimating fecundity of naturally spawning females - rejecting these outliers seemed reasonable. If our intent had been to estimate egg production of broodstock for artificial production, we would have included these females, treating their egg loss as simply part of the operational "costs" to production associated with artificial propagation.

Factorial Crosses: Egg-to-Fry Viability, Developmental Abnormalities and Fry Size

The standard spawning protocol at CESRF is to spawn ripe fish in a series of factorial crosses (Busack *et al*. in prep) typically consisting of 3 females and 3 males, creating 9 single-pair matings (Table 1). In reality, we often have fewer ripe males than

Table 1. Schematic of two 3x3 *inter se* factorial crosses resulting in 9 single pair matings for each cross.

| | | | Male types | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Wild origin | | | Hatchery origin | | |
| | | | W♂1 | W♂2 | W♂3 | H♂1 | H♂2 | H♂3 |
| Female types | Wild origin | W♀1 | | | | No matings | | |
| | | W♀2 | | | | | | |
| | | W♀3 | | | | | | |
| | Hatchery origin | H♀1 | No matings | | | | | |
| | | H♀2 | | | | | | |
| | | H♀3 | | | | | | |

Table 2. A "6 female x 3 male" factorial cross which was often used in 2003 on spawning days when the number of ripe females exceeded the number of males. All males and females are of the same origin.

| | | | Males | | |
|---|---|---|---|---|---|
| | | | ♂1 | ♂2 | ♂3 |
| Females | First cross | ♀1 | | | |
| | | ♀2 | | | |
| | | ♀3 | | | |
| | Second cross | ♀4 | | | |
| | | ♀5 | | | |
| | | ♀6 | | | |

females on a given day and must reuse some portion of available males in a second factorial cross; in effect producing a "6 female by 3 male" factorial cross (Table 2).

In 2003, all factorial crosses made for this report were *inter se* matings. On average, 199 eggs (range: 169 to 275) per female were placed onto a dry 4"x4"plastic weighing tray and approximately 0.2 *cc* (4 drops) of milt from the respective male was dripped over the eggs using a 10 *cc* syringe. The gametes were then placed into a 1 *L* beaker and activated by adding 200 *ml* of well water, gently swirling the contents to insure thorough mixing. After a minimum of 2 minutes post-activation, the eggs from a single-pair mating were decanted and placed into individual incubation containers (isolettes) labeled with the female and male's origin and carcass identification numbers. The isolettes were then placed into an Iodiphore bath for approximately 45 minutes. An isobucket, containing 3 isolettes from one female, was then used to incubate eggs through the eyed egg stage. At that time eggs were shocked, mortalities removed, and the isolettes transferred to Heath trays for final incubation to the post-hatching yolk absorption or "button up" stage.

Isolettes were sampled twice. First, at the eyed egg stage just after shocking when all viable and nonviable eggs were counted. And then a second time, just after yolk absorption, when any additional mortalities were counted. Deformed and abnormal fry (e.g. scoliosis, missing eyes, Siamese twinning, inappropriate fin development or enlarged yolks) were enumerated during this final sampling. Because the viability and deformity data were highly skewed and non-normally distributed, we analyzed them using the nonparametric Kruskal-Wallis 1-way ANOVA to estimate Origin (Hatchery/Wild) effects (Zar 1984).

Fry fork length and body weight were measured on five individuals subsampled from one randomly selected single-pair mating from each female. Thus, not all males are represented in the sample. However, since we were monitoring fry size at the yolk-absorption stage, maternal effects should overwhelm any male effects at this early stage of development (Iwamoto *et al*. 1984; Heath *et al*. 1999). Fry were anesthetized and blotted dry prior to being weighed. Wild and Hatchery origin fry sizes (mean weights and lengths from the 5 fish samples) were compared using ANOVA and weight/length relationships compared via ANCOVA.

Fry Emergence Timing

In order to compare the temporal trends in emergence timing of hatchery and wild fry, we selected a subsample of 16 hatchery and 16 wild females in both 2002 and 2003. We suspected fry emergence traits might be influenced by egg size (see Schroder *et al*. in press), so we selected females representing a broad range of egg sizes. Mean and standard deviation of egg size and other descriptive statistics of the dams used in the emergence study are given in Table 3. In a 2-way (Origin x Year) ANOVA of egg weights, there was no significant Origin ($p$=0.619) or Year ($p$=0.785) effects, nor was there a significant interaction ($p$=0.517). Thus, egg sizes were comparable across Origin in both 2002 and 2003.

| Table 3. Descriptive statistics of hatchery (n=16) and wild (n=16) origin females selected for the fry emergence comparisons in 2002 and 2003. | | | | |
|---|---|---|---|---|
| Year | Origin | Trait | Mean | Sd |
| 2002 | Hatchery | POHP (cm) | 59.0 | 4.3 |
| | | Body weight (kg) | 3.5 | 1.2 |
| | | Egg mass (g) | 675.3 | 199.1 |
| | | Egg weight (g) | 0.180 | 0.029 |
| | | Fecundity | 3744 | 948 |
| | | Reproductive effort | 0.190 | 0.034 |
| | Wild | POHP (cm) | 62.2 | 5.1 |
| | | Body weight (kg) | 4.2 | 1.2 |
| | | Egg mass (g) | 806.8 | 256.4 |
| | | Egg weight (g) | 0.189 | 0.034 |
| | | Fecundity | 4223 | 784 |
| | | Reproductive effort | 0.194 | 0.027 |
| 2003 | Hatchery | POHP (cm) | 65.6 | 4.6 |
| | | Body weight (kg) | 5.0 | 1.2 |
| | | Egg mass (g) | 963.1 | 234.7 |
| | | Egg weight (g) | 0.183 | 0.019 |
| | | Fecundity | 5053 | 1018 |
| | | Reproductive effort | 0.192 | 0.019 |
| | Wild | POHP (cm) | 62.1 | 4.4 |
| | | Body weight (kg) | 4.3 | 1.0 |
| | | Egg mass (g) | 857.6 | 193.3 |
| | | Egg weight (g) | 0.191 | 0.025 |
| | | Fecundity | 4356 | 999 |
| | | Reproductive effort | 0.198 | 0.012 |

An average of 99 eyed eggs (2002 range 93 to 109; 2003 range 83 to 111) from a single-pair *inter se* mating were placed into a PVC chamber filled with plastic saddles as incubation substrate (Fig. 2). Females were randomly assigned to Incubation Chambers (IC). Within each IC, upwelling water flowed at an average rate of 173 ml•5 $sec^{-1}$ (sd=9) and 169 ml•5 $sec^{-1}$ (sd=9) in 2002 and 2003, respectively (Fig. 3). Flows were checked and adjusted every 2-4 days. Incubation water temperature was controlled from the time eggs were fertilized and varied significantly between years (Fig. 4). As fry hatched and developed, they began volitionally moving up out of the substrate, exiting out an opening in the side of the IC and dropping into a screened net-lined 5 gallon bucket (Fig. 2). The buckets were checked daily and fry enumerated and sampled for body weight (BW) to the nearest 1 *mg* and fork length (FL) to the nearest *mm*. Bam's condition index (KD) was calculated (Bams 1970) as an indicator of yolk utilization: $KD = (100 * FL^{0.333})/BW$. Lower KD values indicate more complete yolk utilization (reduced body weight relative to length), while higher values indicate higher yolk reserves. In 2002, eggs were placed into the IC's on November 25 as eyed eggs. Fry began emerging on February 2, 2003 and continued until April 18, 2003. In 2003, eyed eggs were placed into the IC's on

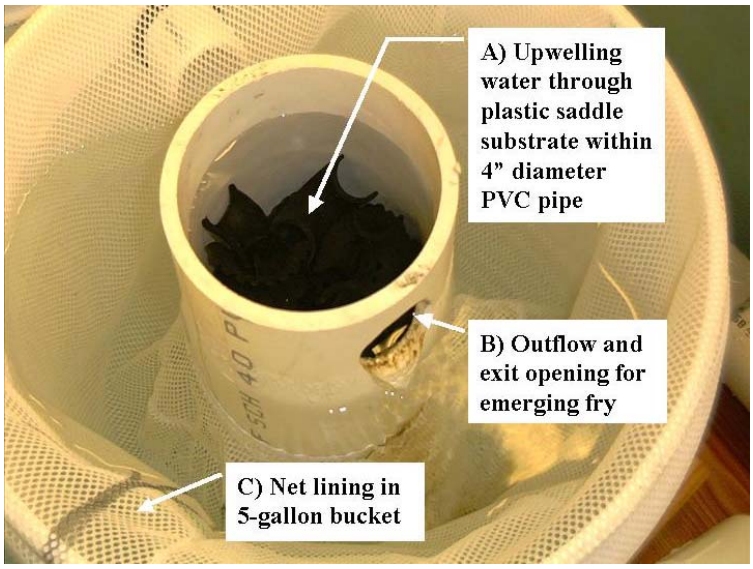



**Figure 2. Fry Incubation Chamber (IC) showing A) the plastic saddle substrate within the PVC pipe, B) the fry exit opening, and C) the net lined 5 gallon holding bucket. An opaque cover was placed over the open end of the PVC pipe containing the substrate.**

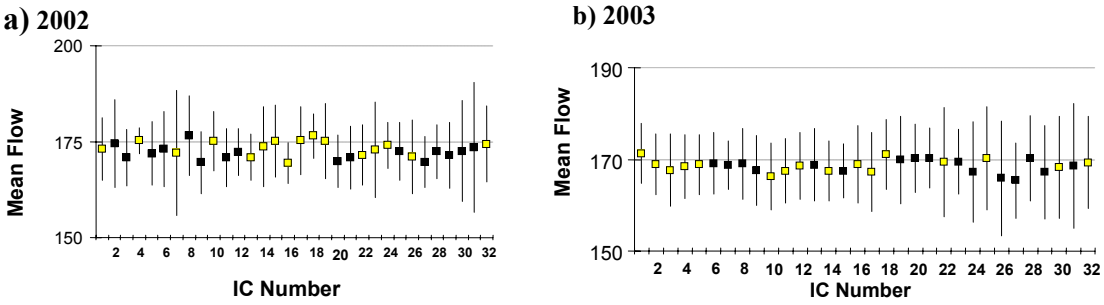



**Figure 3. Mean flow rates (ml/5 sec ±1 sd) by IC number in a) 2002 and b) 2003. Hatchery and wild origin means are in yellow and solid black squares, respectively.**

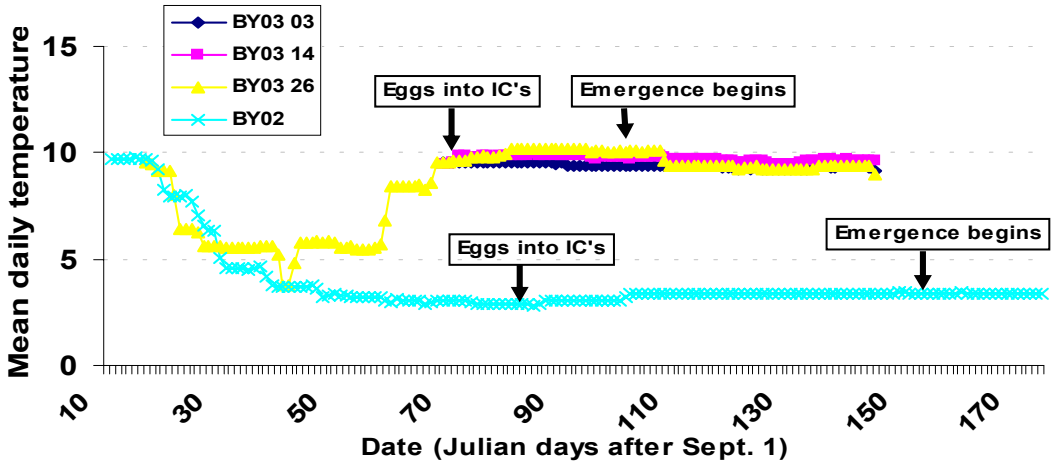



**Figure 4. Mean daily water temperatures for Brood Year 2002 (BY02) and 2003 (BY03). Temperature recorders were placed into isobuckets at the time of fertilization. They were moved to the IC's when the eggs were transferred ("Eggs into IC's").**

November 12 with fry emerging from December 12, 2003 to February 7, 2004. The earlier and shorter emergence period of broodyear 2003 reflects the significantly warmer incubation and rearing water temperatures used that year (Fig. 4).

**Male Testes Traits**

The testes of sexually mature hatchery (n=13) and wild (n=24) origin males were extracted and examined in relation to body size, age and origin. There were no hatchery origin age-2 ("precocious") males and only one age-4 and one age-5 hatchery male sampled, so these age classes were not analyzed for Origin differences. Milt from a mature unspawned male's testes, along with the mesentery containing the gametes, were extracted from the carcass and placed into a tared beaker. The contents were weighed to the nearest 0.1 *g* for males greater than 0.5 *kg* BW and to the nearest 0.01 *g* for age-2 males weighing less than 22 *g*.

To illustrate trait distributions we have used box-whisker plots and these require some explanation (see Figure 5 below). The box-whisker plot shows the median as a horizontal line inside the "box". Within the box lie the central 50% of the distribution's points. The whiskers or vertical lines are $\pm$ 1.5 "inner halves". The location of the median within the box defines the size of the upper and lower "inner halves". In cases where the median, particularly in non-normally and highly skewed distributions, does not fall in the middle of the box, the "inner halves" are not equal and the whiskers will be asymmetrical. Outliers are indicated by an asterisk (∗) and extreme outliers by a circle (○).

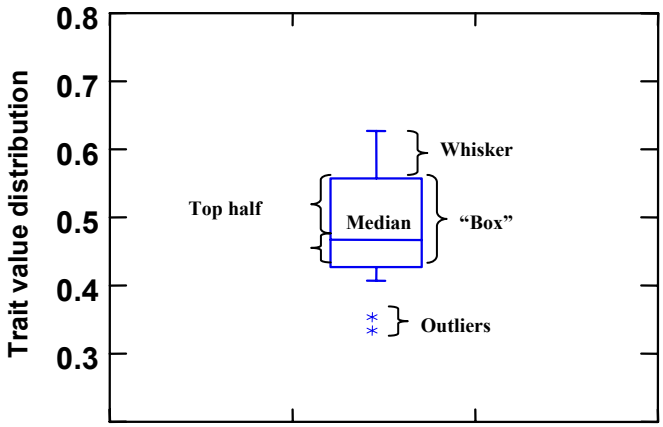



**Figure 5. A box-whisker plot showing the "Box" which encloses the central 50% of the trait's distribution, the median (horizontal line in the box), the whiskers (vertical lines at the top (labeled) and at the bottom), and outliers indicated by an asterisk (*). The top half of the box defines the length of the top whisker.**

# Results

## Fecundity and Fecundity/Female Size Relationship

Fecundity distributions for age-4 and -5 hatchery and wild origin females selected for broodstock are shown in Figure 6. Mean hatchery age-4 fecundity was 3,907 (n=28; sd=853), wild age-4 fecundity was 4,349 (n= 162; sd=748), hatchery age-5 fecundity was 5,732 (n=19; sd=832), and wild age-5 fecundity was 5,427 (n= 30; sd=1,118). Age-4 hatchery females had significantly fewer eggs (11% less fecund) than wild females (1-way ANOVA, $p$=0.006). There was no significant difference between age-5 females (1-way ANOVA, $p$=0.302).

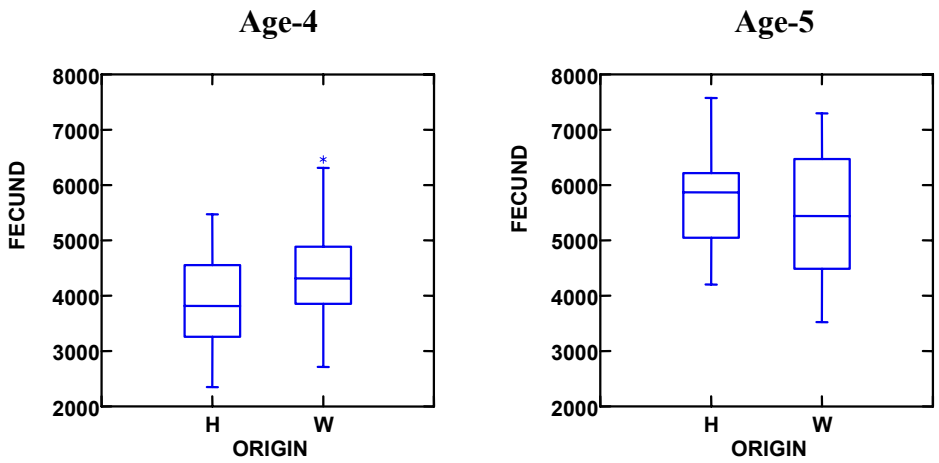



**Figure 6. Fecundity distributions of age-4 and -5 hatchery (H) and wild (W) origin females in 2003. All females have reproductive effort values greater than or equal to 0.14.**

There was a strong, positive correlation between fecundity and body size at spawning in both hatchery and wild origin females ($p$<0.01; Table 4 and Fig. 7). In an ANCOVA comparing hatchery and wild females, there was no significant difference between the slopes of the age-4 regressions (POHP $p$=0.145 equivalent slopes; Body weight $p$=0.376 equivalent slopes) or the age-5 regressions (POHP $p$=0.702 equivalent slopes; Body weight $p$=0.471 equivalent slopes). Comparing the within-origin slopes of age-4 and -5 females showed no significant difference between the two age classes (ANCOVA; $p$>0.09 equivalent slopes).

| Table 4. Results of linear regression analyses estimating fecundity using either female POHP length or female body weight for age-4 and -5 wild and hatchery origin females in 2003. | | | | | |
|---|---|---|---|---|---|
| Origin Age | Effect | Coefficient | Regression SE | $r^2$ | Regression *p*-value |
| Wild Age-4 (n=162) | Constant | 1074.7 | 520.5 | 0.519 | <0.001 |
| | Body Wt | 799.0 | | | |
| | Constant | -5020.9 | 526.5 | 0.508 | <0.001 |
| | POHP | 153.1 | | | |
| Wild Age-5 (n=30) | Constant | 908.9 | 876.1 | 0.407 | <0.001 |
| | Body Wt | 772.3 | | | |
| | Constant | -6139.3 | 926.8 | 0.336 | 0.001 |
| | POHP | 166.4 | | | |
| Hatchery Age-4 (n=28) | Constant | 371.2 | 522.4 | 0.639 | <0.001 |
| | Body Wt | 932.2 | | | |
| | Constant | -8308.0 | 569.1 | 0.571 | <0.001 |
| | POHP | 203.6 | | | |
| Hatchery Age-5 (n=19) | Constant | 2199.1 | 599.5 | 0.510 | 0.001 |
| | Body Wt | 595.5 | | | |
| | Constant | -4093.3 | 688.0 | 0.354 | 0.007 |
| | POHP | 139.8 | | | |

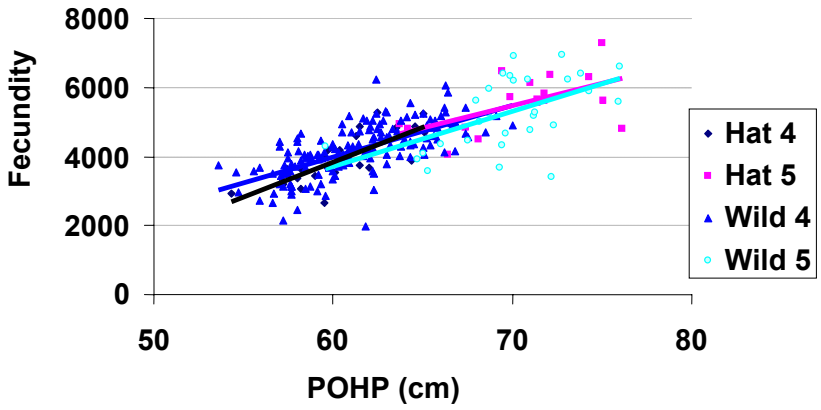



**Figure 7. Linear relationship between CERSF POHP length and fecundity for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

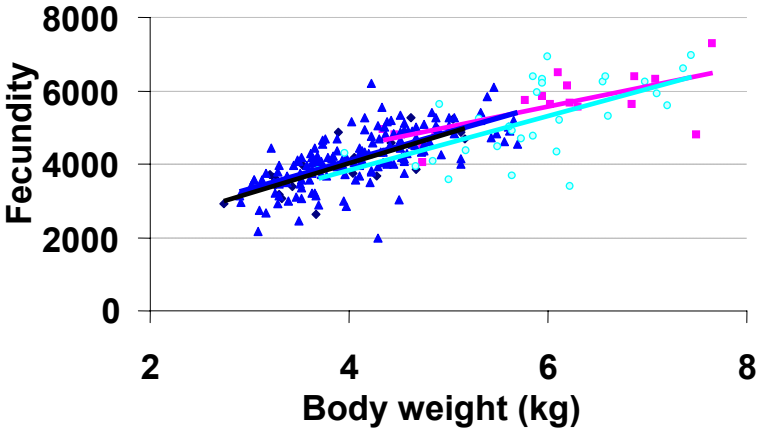



**Figure 8. Linear relationship between CERSF body weight and fecundity for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

In order to develop a more precise estimator of fecundity, particularly for use in estimating the fecundity of females used in the CESRF spawning channel, we used multiple linear regression including female body weight, POHP length and mean egg size to estimate fecundity (Table 5). Body weight was significant in all regressions ($p<0.01$). Mean egg size was significant ($p<0.01$) in all regressions but hatchery age-5's (p=0.10), while POHP was not significant in any regression ($p> 0.16$). Including body weight, egg weight and POHP in the fecundity regressions explained 59-78% of the total variation with SE's of 365 to 531, while any one of the three variables alone explained 0 to 64% of the total variation with SE's ranging from 521 to 1017. These are very similar to results from 2002 returns.

Table 5. Multiple regression results using mean egg weight, POHP length and female body weight to estimate fecundity. The significance of each variable's contribution to the overall regression equation is given (*p*-value), as is the regression's standard error (SE) and adjusted $r^2$.

| Origin | Effect | Coefficient | *p*-value | SE | Adjusted $r^2$ |
|---|---|---|---|---|---|
| Wild Age-4 (n=162 ) | Constant | 4794.2 | <0.001 | 365.4 | 0.761 |
| | Egg Wt | -17526.7 | <0.001 | | |
| | POHP | -32.3 | 0.162 | | |
| | Body Wt | 1170.8 | <0.001 | | |
| Wild Age-5 (n= 30) | Constant | 6680.2 | 0.067 | 529.7 | 0.776 |
| | Egg Wt | -22950.0 | <0.001 | | |
| | POHP | -45.5 | 0.541 | | |
| | Body Wt | 1143.3 | 0.001 | | |
| Hatchery Age-4 (n= 28) | Constant | 2541.6 | 0.436 | 406.9 | 0.772 |
| | Egg Wt | -13081.4 | <0.001 | | |
| | POHP | -16.8 | 0.813 | | |
| | Body Wt | 1269.3 | 0.001 | | |

Table 5. cont'd Multiple regression results using mean egg weight, POHP length and female body weight to estimate fecundity. The significance of each variable's contribution to the overall regression equation is given (*p*-value), as is the regression's standard error (SE) and adjusted $r^2$.

| Origin | Effect | Coefficient | *p*-value | SE | Adjusted $r^2$ |
|---|---|---|---|---|---|
| Hatchery (n= 19) | Constant | 12089.4 | 0.062 | 530.6 | 0.593 |
| | Egg Wt | -11394.5 | 0.100 | | |
| | POHP | -167.5 | 0.190 | | |
| | Body Wt | 1295.1 | 0.007 | | |

Egg Weight

Based on egg weight data from females spawned at CESRF in 2003 (Fig. 9), age-4 (mean=0.184 g; n=31) and -5 (mean=0.200 g; n=20) year old hatchery females had slightly smaller eggs than wild age-4 (mean=0.188 g; n=169) and -5 year old (mean=0.208 g; n=30) females. Neither age demonstrated a significant difference due to Origin (2-way ANOVA Origin effect; $p$=0.292). As in previous years, age-5 females' eggs were significantly larger than age-4 females' (2-way ANOVA: Age effect $p$<0.001; interaction effect $p$=0.496).

There was a positive relationship between female body size and egg weight in 2003 (Table 6; Fig. 10 and 11). The relationship was significant ($p$<0.03) for all females, except wild origin age-5's ($p$=0.19). The relationships explained as much as 26% of the total variation in egg weight, compared to 2002 when no more than 6% was explained.

The relationship between egg weight and fecundity (Fig. 12) was not significant for hatchery origin females ($p$>0.76), but was negative and significant in wild females ($p$=0.01). The relationship explained 4 and 17% of egg weight variation in wild age-4 and -5 females, respectively.

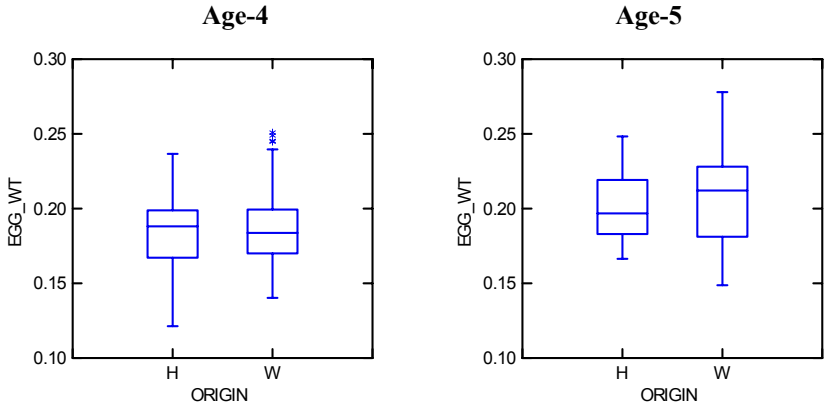



**Figure 9. Box-whisker plots of egg weights (*g*) of age-4 and -5 hatchery (H) and wild (W) origin females in 2003.**

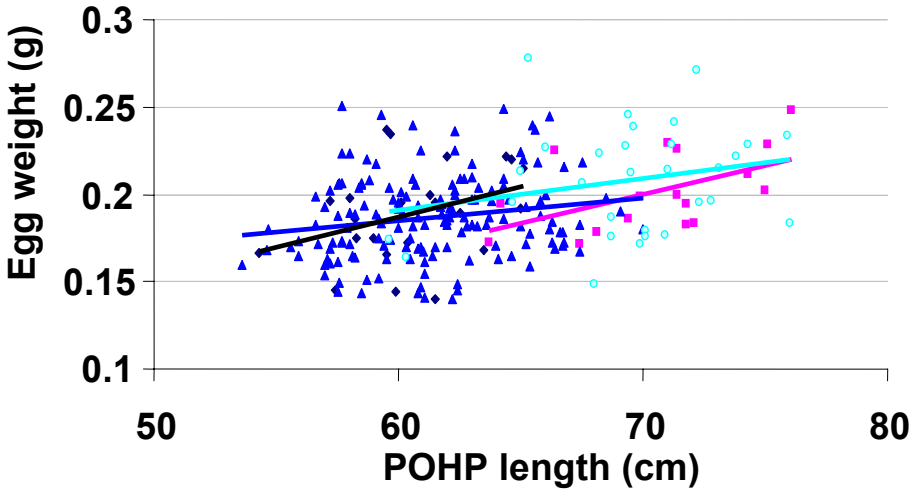



**Figure 10. Linear relationship between CERSF female POHP length and egg weight for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

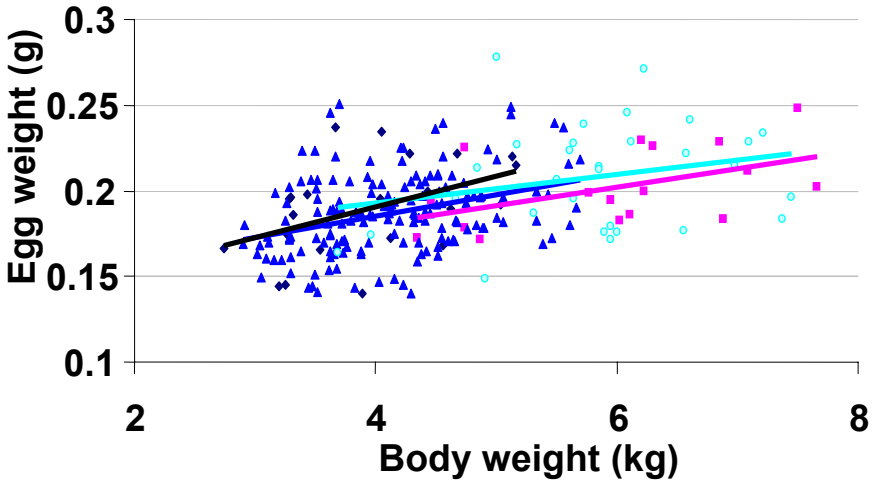



**Figure 11. Linear relationships between female body weight and "green" individual egg weight for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

Table 6. Results of linear regression analyses estimating egg weight using either female POHP length or female body weight for age-4 and -5 wild and hatchery origin females in 2003.

| Origin Age | Effect | Coefficient | Regression SE | $R^2$ | Regression *p*-value |
|---|---|---|---|---|---|
| Wild Age-4 (n=162) | Constant | 0.135 | 0.022 | 0.122 | <0.001 |
| | Body Wt | 0.012 | | | |
| | Constant | 0.103 | 0.023 | 0.035 | 0.010 |
| | POHP | 0.001 | | | |
| Wild Age-5 (n=30) | Constant | 0.160 | 0.031 | 0.027 | 0.192 |
| | Body Wt | 0.008 | | | |
| | Constant | 0.079 | 0.031 | 0.019 | 0.220 |
| | POHP | 0.002 | | | |
| Hatchery Age-4 (n=28) | Constant | 0.109 | 0.027 | 0.220 | 0.007 |
| | Body Wt | 0.021 | | | |
| | Constant | -0.059 | 0.028 | 0.154 | 0.022 |
| | POHP | 0.004 | | | |
| Hatchery Age-5 (n=19) | Constant | 0.029 | 0.021 | 0.208 | 0.028 |
| | Body Wt | 0.005 | | | |
| | Constant | -0.051 | 0.020 | 0.259 | 0.015 |
| | POHP | 0.004 | | | |

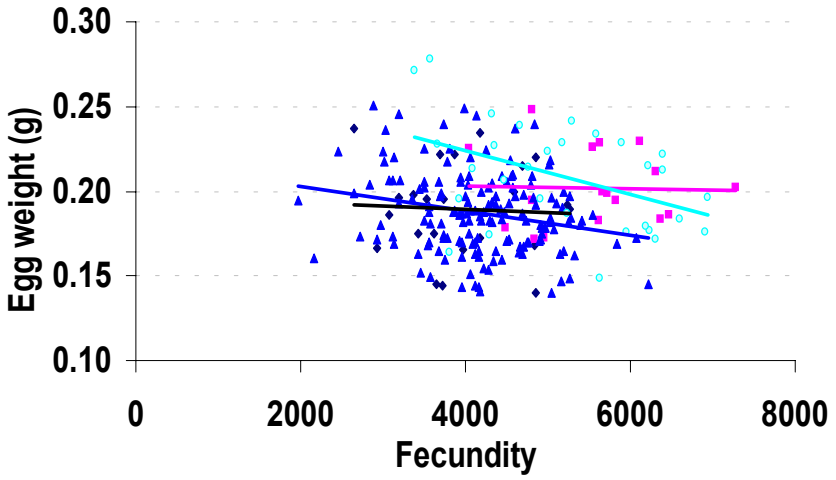



**Figure 12. Linear relationships between fecundity and "green" individual egg weight for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

Gamete Weight and Reproductive Effort

Reflecting the results for fecundity, gamete weight was significantly greater for wild age-4 females (mean= 812 *g*) compared to age-4 hatchery females (mean= 732 *g*; $p$=0.018; Fig. 13). Age-5 hatchery females (mean= 1150 *g*) had greater mean gamete weight than wild age-5 females (mean= 1115 *g*), but the difference was not significant ($p$=0.584).

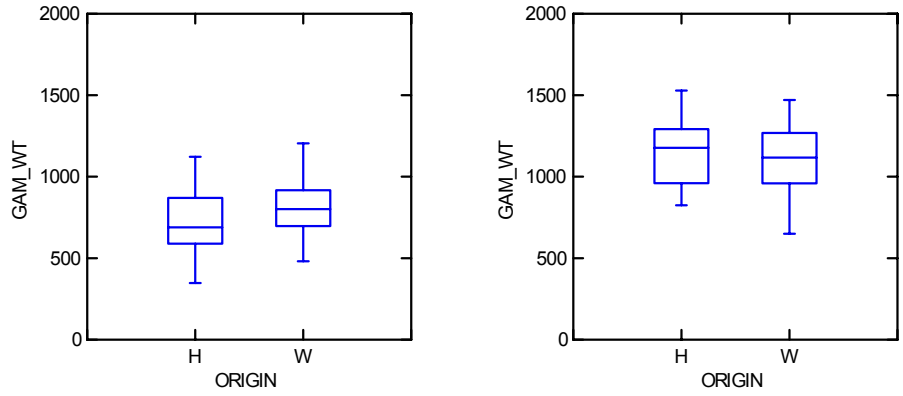



**Figure 13. Box-whisker plots of gamete weight (GAM_WT) in grams for age 4 and -5 wild and hatchery origin females in 2003.**

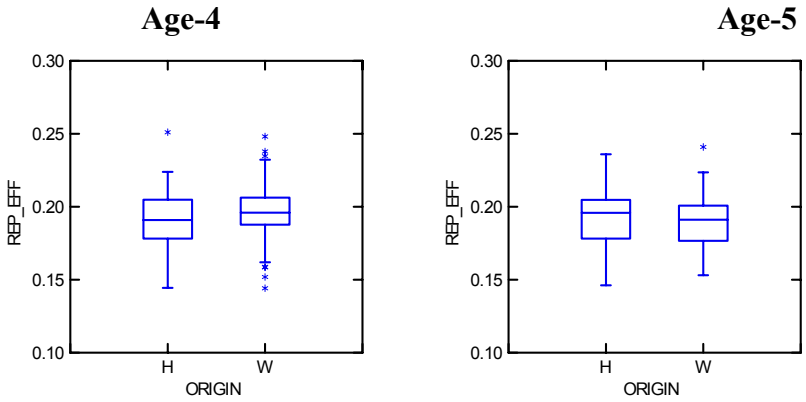



**Figure 14. Box-whisker plots of reproductive effort (REP_EF) for age-4 and -5 hatchery and wild origin females in 2003.**

Female Reproductive Effort (RE), the ratio of the total weight of a female's gametes to total body weight, represents the proportion of total somatic growth allocated to gamete production. As in 2002 returns, mean RE values across all groups of females in 2003 were similar (Fig. 14). The RE of age-4 hatchery females (mean=0.190; n=28) was less than wild females (mean=0.197; n= 162), while hatchery age-5 wild females (mean=0.193; n= 16) had higher mean RE than wild age-5's (mean=0.190; n= 30). In a

2-way ANOVA there was no significant Origin ($p$=0.598), Age ($p$=0.618), or interaction ($p$=0.165) effects. Thus, all females, irrespective of age and origin, were producing equivalent grams of gametes per *kg* of body weight.

## Relative Fecundity

Relative Fecundity (RF) standardizes fecundity or egg productivity to a "per unit body size" metric, e.g. number of eggs•(*kg* body weight)$^{-1}$. Within age classes, females of each origin were similar (Fig. 15). Wild age-4 females (1068 eggs•(*kg* body weight)$^{-1}$) had mean RF values that were slightly greater than hatchery females (1034 eggs•(*kg* body weight)$^{-1}$), while age-5 wild females (932 eggs•(*kg* body weight)$^{-1}$) had slightly lower RF than hatchery female's (976 eggs•(*kg* body weight)$^{-1}$). In a 2-way ANOVA there was no significant Origin effect ($p$=0.838) or interaction effect ($p$=0.109). There was a significant difference between the two age classes ($p$<0.001). Thus, on average the fecundity of age-5 females is approximately 10% lower than one would expect from age-4 females of the same body weight, because older females are producing fewer, larger eggs per *kg* body weight.

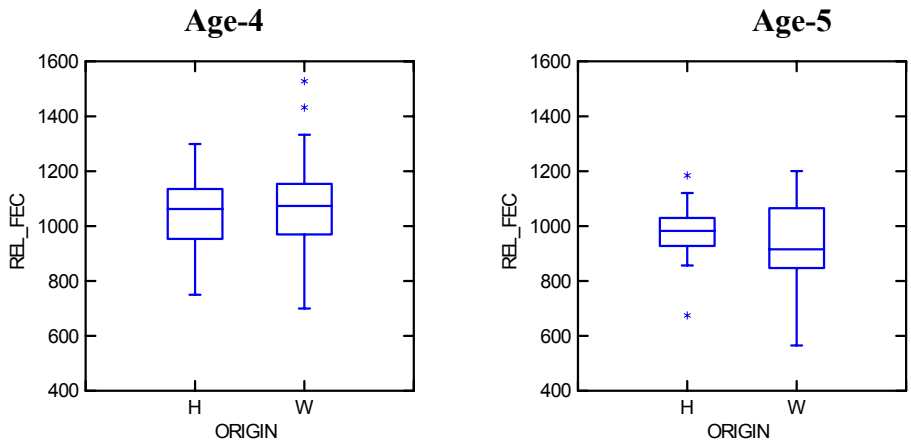



**Figure 15. Box-whisker plots of relative fecundity (REL_FEC; eggs/kg body weight) for age-4 and -5 hatchery and wild origin females in 2003.**

Relative Fecundity vs. Egg Weight and RE

Regressing egg weight or RE against RF illustrates how females manage the tradeoffs between somatic growth and gametes or egg size as RF changes (Table 7; Fig. 16). RE and RF were positively correlated for all females ($r^2$>0.21; $p$<0.03), except hatchery age-4's ($r^2$=0.01; $p$=0.28). Egg weight and RF was negatively correlated across all female groups ($r^2$ ranged between 0.18 and 0.48; $p$<0.02; Fig. 16B).

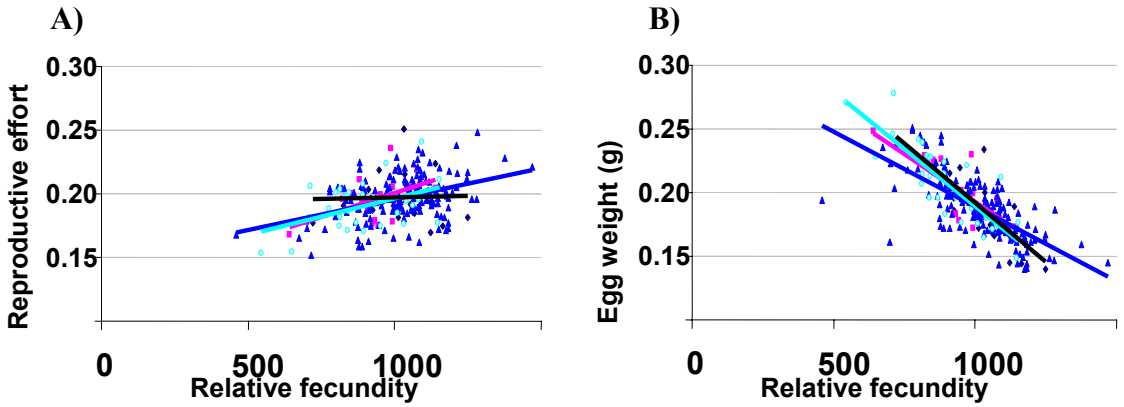



**Figure 16. Relationship of A) reproductive effort and B) egg weight to relative fecundity (eggs/kg body weight) for hatchery age-4 (♦) and age-5 (■) origin and wild age-4 (▲) and age-5 (●) origin upper Yakima River spring chinook in 2003.**

Table 7. Results of linear regression analyses estimating either reproductive effort (RE) or egg weight from relative fecundity (RF) for age-4 and -5 wild and hatchery origin females in 2003.

| Origin Age | Effect | Coefficient | Regression SE | $R^2$ | Regression $p$-value |
|---|---|---|---|---|---|
| Wild Age-4 (n=162) | Constant | 0.32751 | 0.016 | 0.556 | <0.001 |
| | Egg wt | -0.00013 | | | |
| | Constant | 0.14511 | 0.016 | 0.133 | <0.001 |
| | RF | 0.00005 | | | |
| Wild Age-5 (n=30) | Constant | 0.36799 | 0.018 | 0.687 | <0.001 |
| | Egg wt | -0.00017 | | | |
| | Constant | 0.13987 | 0.017 | 0.168 | 0.014 |
| | RF | 0.00005 | | | |
| Hatchery Age-4 (n=28) | Constant | 0.33421 | 0.023 | 0.417 | <0.001 |
| | Egg wt | -0.00014 | | | |
| | Constant | 0.15127 | 0.025 | 0.007 | 0.284 |
| | RF | 0.00004 | | | |
| Hatchery Age-5 (n=19) | Constant | 0.32151 | 0.019 | 0.324 | 0.006 |
| | Egg wt | -0.00013 | | | |
| | Constant | 0.10300 | 0.018 | 0.217 | 0.026 |
| | RF | 0.00009 | | | |

Egg Viability and Developmental Abnormalities

There was no significant Origin effect when egg viability distributions of hatchery (median viability =0.925; n=20) and wild (median viability =0.921; n=18) origin females were compared (Fig. 17) using a Kruskal-Wallis 1-way ANOVA ($p$=0.579). As in past years, abnormally developing fry were relatively rare in both hatchery and wild samples (Fig 18). Median percentages of hatchery and wild fry with abnormalities were 0.2% and 0.4%, respectively, which were not significantly different (Kruskal-Wallis 1-way ANOVA; $p$=0.327).

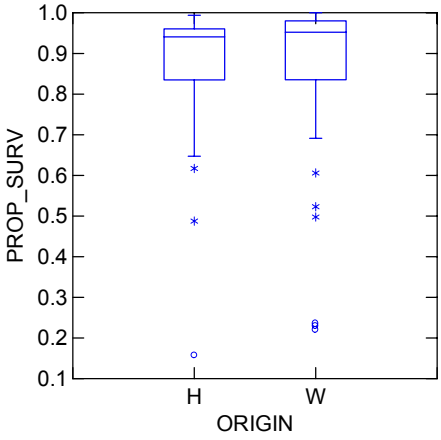



**Figure 17. Box-whisker plot of hatchery and wild origin female egg-to-fry survival proportions in 2003.**

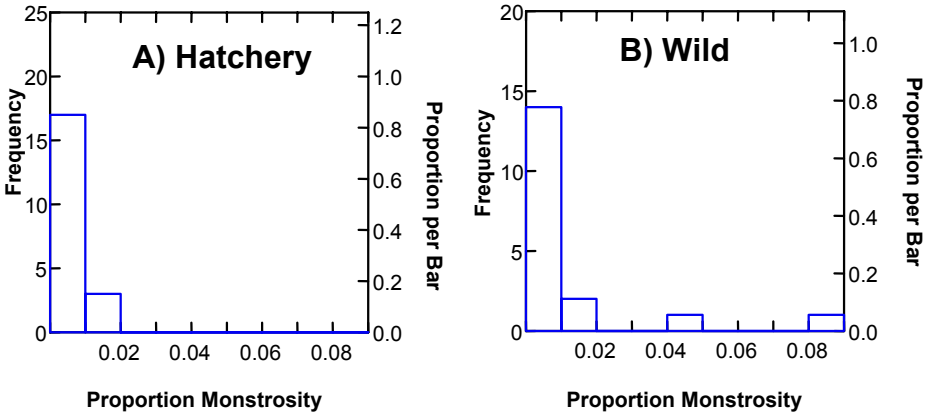



**Figure 18. Frequency distribution of monstrosity/deformity counts for A) Hatchery and B) Wild fish in 2003 based on isolette samples.**

**Fry Size**

Wild fry (34.8 *mm*, 0.31 *g* and 1.38 *KD*) were equivalent in size to hatchery fry (34.7 *mm*, 0.31 *g* and 1.38 *KD*) demonstrating no significant differences in 1-way ANOVAs testing for Origin effects ($p>0.60$). Egg weight was positively correlation with fry length ($r^2 \geq 0.583$; $p<0.001$; Fig. 19) and fry weight ($r^2 \geq 0.823$; $p<0.001$; Fig. 20). Results from ANCOVA indicated that hatchery and wild fry have equal fry weight/egg weight and fry length/egg weight slopes ($p \geq 0.315$). Hatchery and wild fry also had equivalent fry length/fry weight slopes ($p=0.468$; Fig. 21).

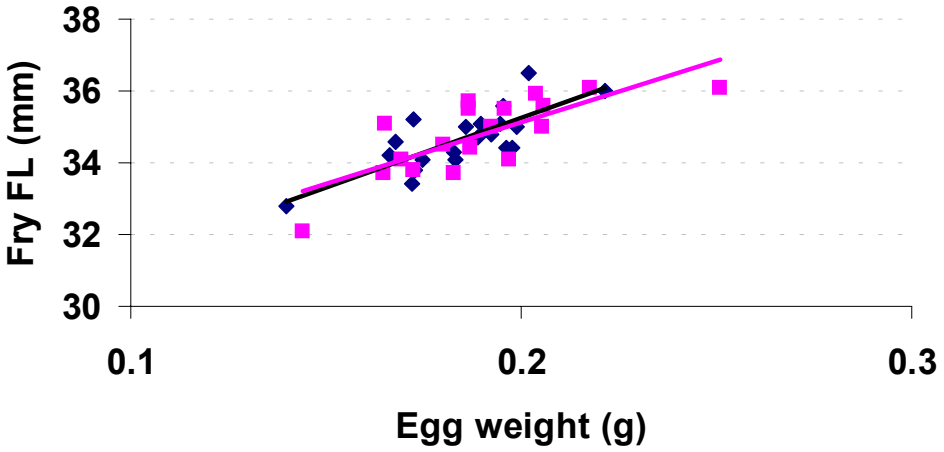



**Figure 19. Relationship between fry fork length and egg weight for hatchery (♦; n=20) and wild (■; n=18) origin spring chinook from the 2003 brood.**

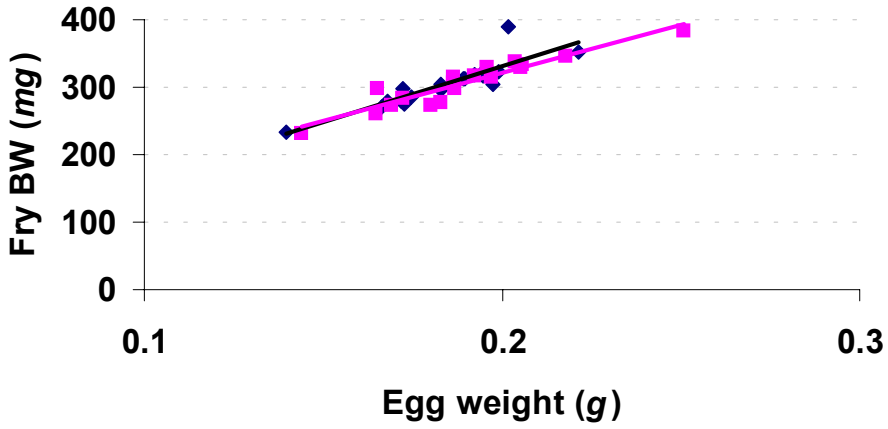



**Figure 20. Relationship between fry weight and egg weight for hatchery (♦; n=20) and wild (■; n=18) origin spring chinook from the 2003 brood.**

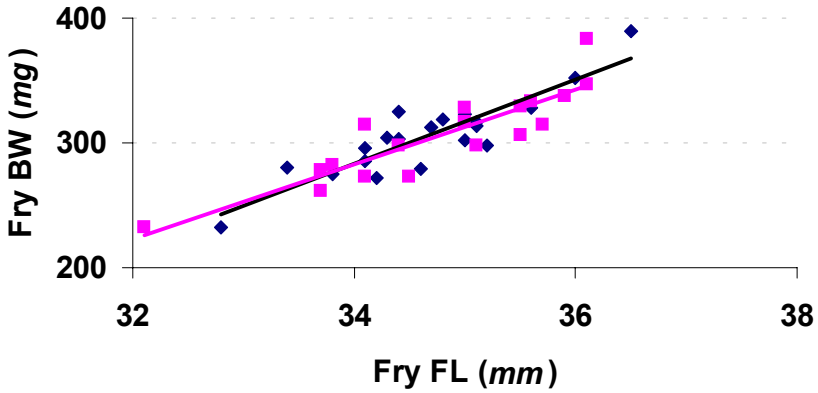



**Figure 21. Comparison of hatchery (♦) and wild (■) origin fry body weight (BW) versus fry fork length (FL) for progeny of 2003 upper Yakima River spring chinook.**

There were no significant correlations between female body weight and fry size (Table 8; Fig. 22 and 23). Hatchery females exhibited the only significant female POHP/Fry FL relationship ($p$=0.05) which explained 15% of the total variation in fry length. Thus, in 2003 female body size had at most only a relatively weak influence on fry size at emergence. Our sample sizes in 2003 were small compared to 2002 (Hatchery n=34; Wild n=36) reducing the statistical power of these regressions. However, the 2003 results were very similar to 2002, both quantitatively and qualitatively.

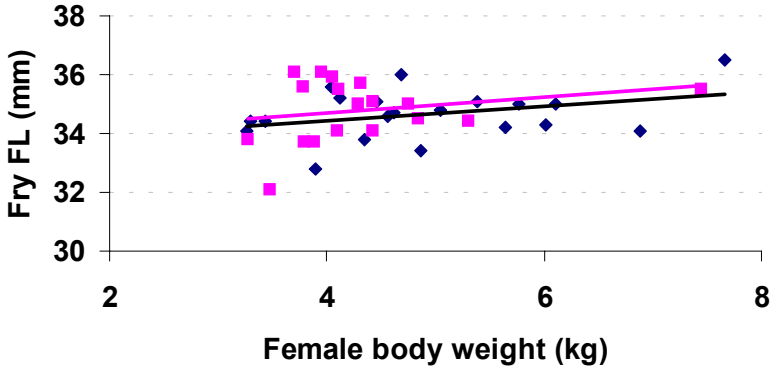



**Figure 22. Linear relationship between female body weight and fry fork length in hatchery (♦) and wild (■) origin spring chinook in 2003.**

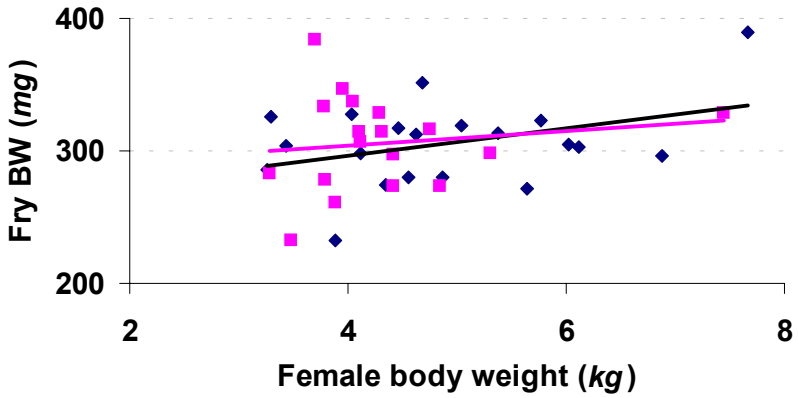



**Figure 23. Linear relationship between female body weight and fry body weight in hatchery (♦) and wild (■) origin upper Yakima River spring chinook.**

Table 8. Linear relationships between female body weight (FW) and POHP length (FemL) to fry fork length (FryLn) and fry body weight (FryBW) by origin for 2003 upper Yakima River spring chinook.

| Relationship | ♀ Origin | $R^2$ | *p*-value | n |
|---|---|---|---|---|
| FW by FryLn | Hatchery | 0.069 | 0.139 | 20 |
| | Wild | <0.001 | 0.332 | 18 |
| FW by FryBW | Hatchery | 0.096 | 0.099 | 20 |
| | Wild | <0.001 | 0.576 | 18 |
| FemL by FryLn | Hatchery | 0.147 | 0.053 | 20 |
| | Wild | <0.001 | 0.853 | 18 |
| FemL by FryBW | Hatchery | 0.021 | 0.251 | 20 |
| | Wild | <0.001 | 0.576 | 18 |

## Fry Emergence

In 2002, Hatchery (n=1579) and Wild (n=1578) fry emergence median dates were essentially equal, differing by less than 1 day (Fig. 24). This was also true of the range in emergence timing. A Kruskal-Wallis (K-W) nonparametric ANOVA comparing emergence timing distributions was not significant ($p$=0.114). In 2003, the Wild origin fry (n=1579) median emergence date was 3 days later than Hatchery (n=1588) origin fry (Fig. 25) and occurred over a 4 day shorter period of time (Hatchery range = 57 days; Wild range = 53 days). A K-W ANOVA comparing 2003 emergence timing distributions was significant ($p$<0.001).

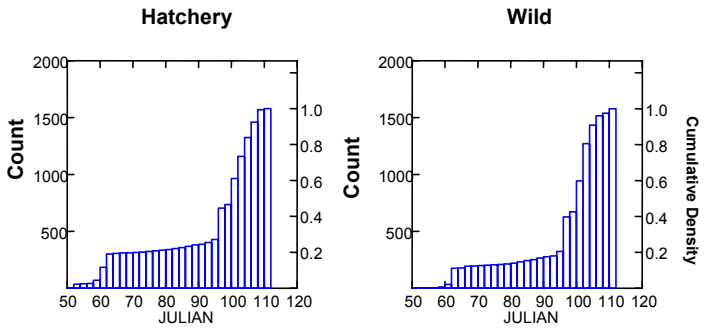



**Figure 24. Emergence timing cumulative distributions for Hatchery and Wild origin fry in 2002. Median dates and ranges of emergence timing differed by no more than 1 day.**

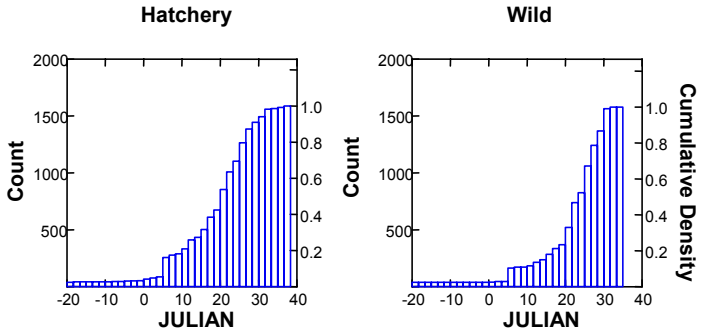



**Figure 25. Emergence timing cumulative distributions for Hatchery and Wild origin fry in 2003. Wild fry median date of emergence was 3 days later than hatchery origin fry while Hatchery fry range in emergence timing was 4 days longer than wild fry.**

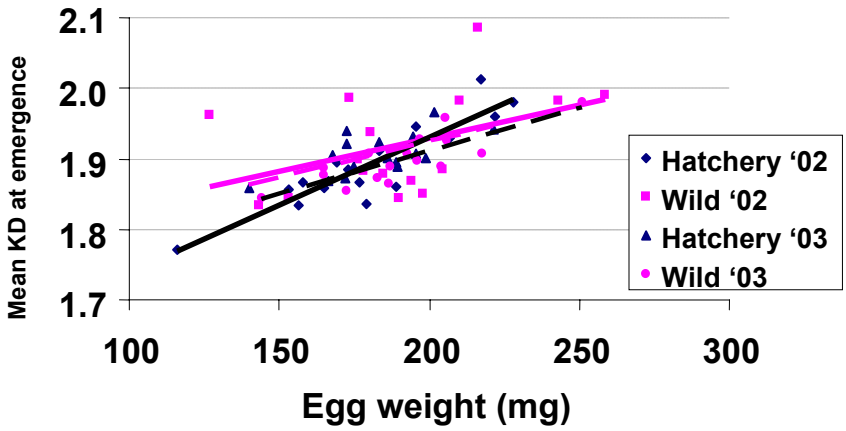



**Figure 26. Egg weight versus mean KD at emergence for BY2002 (solid lines) and 2003 (dashed lines) by origin. Mean KD is calculated from fry captured over the entire emergence period for an IC.**

For 2002 and 2003, we compared the relationship of KD of emerging fry to their egg weight by origin (Fig. 26). There was a significant positive relationship with increasing KD values with increasing egg weight for both hatchery and wild fry ($R^2$>0.42, $p$<0.001). Based on ANCOVA, the slopes of hatchery and wild fry were not significantly different (equal slopes $p$=0.262).

## Male Testes/Body Size Relationships

Due to small sample sizes only the age-3 component could be tested for Origin effects. Wild and Hatchery origin age-3 males did not exhibit significant differences in either mean testes weight, log(testes weight)/log(body size) relationships, or Reproductive Effort. Testes weight was positively correlated with body size across ages and age-2, -3 and -4 males each had significantly different mean testes weights (ANOVA $p$<0.01; Fig. 28). Age-2 males had a mean RE of 13.2%, which was significantly higher than in age-3 (5.7%) and -4 (6.1%) males. Thus, age-2 males allocate over twice the proportion of their total body weight toward gamete production relative to older males (Fig. 29) indicating a significant reprioritization of energy allocation toward gametes.

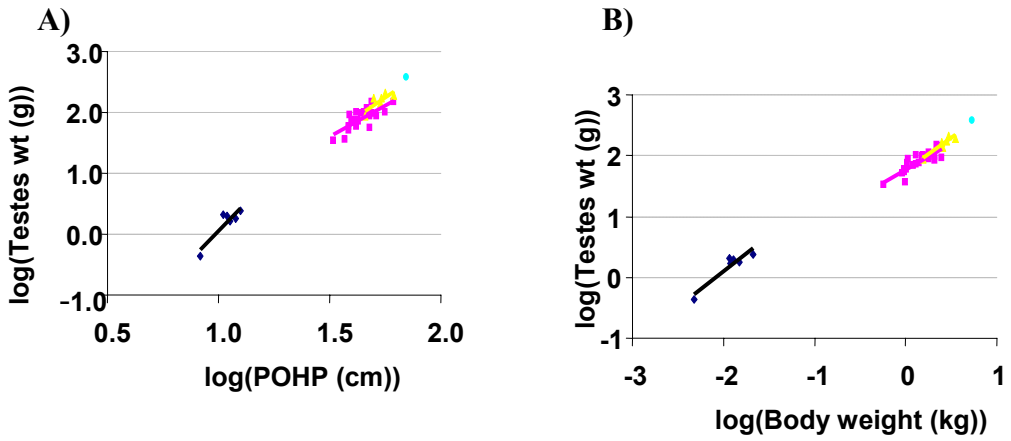



**Figure 28. Log(testes weight) versus A) log(POHP) length and B) log(body weight) for age-2 (♦), -3 (■), -4 (▲) and -5 (●) males in 2003. Hatchery and wild fish have been combined.**

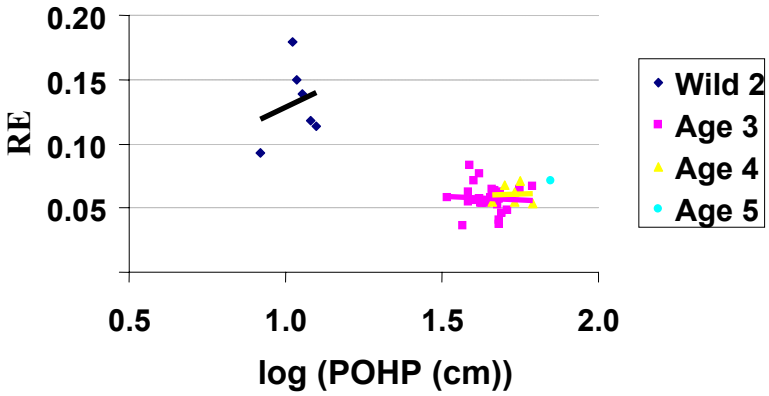



**Figure 29. Reproductive effort (RE) versus POHP length for age-2 (♦), -3 (■), -4 (▲) and -5 (●) males in 2003. Wild and Hatchery males have been combined.**

## Discussion

Any differences in heritable traits of CESRF hatchery and upper Yakima River wild origin fish would have to be due to the effects of a single generation of domestication driven by either unintentional directional selection and/or relaxation of natural selection pressures in the hatchery. Trait differences can also have a non-genetic basis, caused by phenotypic plasticity due to environmental variation (Riddell 1986). A common example of this is larger size and later release of hatchery fish relative to wild conspecifics. This typically occurs because larger fish released later often experience higher survival (Bilton *et al*. 1982). Hatchery smolts are larger at release than naturally rearing conspecifics because of the hatchery environment (rearing/feed regime) and outmigrate later due to human intervention (release timing). Thus, these trait differences would exist even if the two groups came from the same families. However, these environmentally induced differences in rearing and release timing can cause changes in adult phenotypic traits such as reduced age at maturity (Beatty 1996; Larsen *et al.* 2004) and size-at-return in hatchery chinook (Unwin and Glova 1997) and coho salmon (Bilton *et al.* 1982). In reality, observed trait differences are likely to be due to complex combinations of both environmental and genetic factors affecting trait expression that will vary in intensity from year to year. The YKFP has begun implementation of a domestication study (Busack *et al.* 2002) to help identify the magnitude of the genetic component in any observed trait differences.

In the 2001 and 2003 returns, we observed a significant decrease in fecundity in hatchery fish relative to wild fish as a direct consequence of reduced hatchery size-at-age (Knudsen *et al*. 2002a). Hatchery fish were also smaller that wild fish in 2002 and had lower fecundity, but the fecundity difference was not statistically significant. This was due in part to hatchery and wild fish having similar RE means, but hatchery egg weight was 4% lower than wild egg weight resulting in higher hatchery relative fecundity (1089

eggs•(kg body weight)$^{-1}$) than wild females (1049 eggs•(kg body weight)$^{-1}$). This higher egg production per unit body weight compensated somewhat for their smaller size.

Heath *et al*. (2003) found that females from captive brood spring chinook populations produced smaller eggs than wild females, which they attributed to a combination of relaxation of natural selection pressures for larger egg size and intentional selection for higher fecundity. We have not found a similar trend. For the dominant age-4's, mean egg weights in 2002 were significantly different, while 2001 and 2003 were

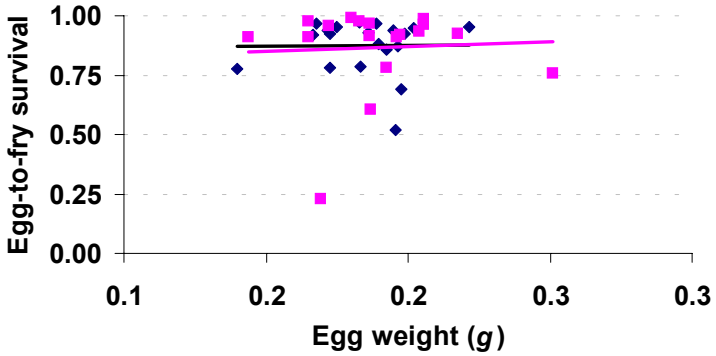



**Figure 30. Log-log transformed linear regression of egg weight and egg-to-fry survival for both hatchery (♦) and wild (■) females were not significantly different from 0.0 ($p$>0.63).**

not. We did find that age-4 hatchery origin eggs were significantly smaller in 2002. Heath *et al*. also found that egg size was positively correlated with fry survival. However, as in 2002 we found no evidence of a similar significant correlation in log-log transformed egg-to-fry survival vs egg weight (Fig. 30).

In 2001 and 2002, we observed significant differences in the fecundity/body size relationships of age-4 and -5 females irrespective of origin. Age-4 females had steeper slopes and significant correlations, while age-5's showed no, or a much weaker, relationship. Age-4 females were approximately 50% more productive per unit body size. This trend was not repeated in 2003 and the age classes were more similar in productivity due primarily to the 2003 age-5 females demonstrating a much stronger correlation between fecundity and body size.

The allocation of energy between gamete production, somatic growth and behavior affects female and male fitness. There are significant trade offs made between energy budgeted toward gametes and other "bins" such as migration, body size, secondary sexual characteristics, competition and nest guarding (Kinnison *et al* 2001) and the allocation between all "bins" should coevolve under selection pressures so that lifetime reproductive success will be maximized (Pianka 1976; Roff 1988). For a self-sustaining population of naturally spawning fish, shifting the gamete biomass "bin" away from the optimum will divert energy from some other aspect of growth or behavior that

has also been shaped by natural selection. For females we have observed that RE values for hatchery and wild females have been remarkably similar from 2001 to 2003 and across age classes. For males, the age-2 males have shifted a significant amount of energy into gametes allocating twice as much body weight to testes as the age-3 and older males. This is likely an adaptation associated with this life history strategy to help overcome their extreme size disadvantage during spawning.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

## Acknowledgements

The help of the Yakama Nation Cle Elum Supplementation Research Facility personnel was greatly appreciated and their cooperation during the period of artificial spawning made this work possible. Todd Newsome (YN), Ann Stephenson (YN), Joel Hubble (YN), Dana Anderson (WDFW) and Lang Ngyuen (WDFW) provided help sampling broodstock during spawning at CESRF. Gene Sandborn (WDFW) designed and installed the Incubation Chambers used at CESRF. Bill Bosch (YN) provided valuable help in overall data management and information access during 2003. Finally, we also thank David Byrnes (Bonneville Power Administration) for securing and administering funding for this work.

## References

Bageal, T.B. 1969. The relationship between food supply and fecundity in brown trout, *Salmo trutta* L. J. Fish Biology 1:167-182.

Bams, R. 1970. Evaluation of a revised hatchery method tested on pink and chum salmon fry. J. Fish. Res. Bd. Canada 27:1429-1452.

Beacham,T.D., and C.B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). J. Fish Biol. 42:485-508.

Beaty, R.E. 1996. Changes in the size and age at maturity of Columbia River upriver bright fall chinook salmon (*Oncorhynchus tshawytscha*): Implications for stock fitness, commercial value and management. Technical report (Columbia River Inter-Tribal Fish Commission) 96-7.

Beckman, B., D. Larsen, C. Sharpe, B. Lee-Pawlak, C. Schreck, W. Dickhoff. 2000.

Physiological status of naturally reared juvenile spring chinook salmon in the Yakima River: Seasonal dynamics and changes associated with smolting. Trans. Am. Fish. Soc. 129(3):727–753.

Beer, W.N., and J.J. Anderson. 2001. Effect of spawning day and temperature on salmon emergence: interpretations of a growth model for Methow River chinook. Can. J. Fish. Aquat. Sci. 58:943-949.

Bilton, H. , D. Alderdice, and J. Schnute. 1982. Influence of time and size of release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Can. J. Fish. Aquat. Sci. 43:281-287.

Blouin, M. 2003. Relative reproductive success of hatchery and wild steelhead in the Hood River. Final report, BPA Intergovernmental Contract 9245, Project # 1988-053-12.

Busack, C., C. Knudsen, and S. Phelps. 2004. Modelling the effective size advantage of factorial mating in hatcheries. *In* Washington Department of Fish and Wildlife Genetics Studies. BPA Annual Report 2003.

Busack, C., C. Knudsen, D. Seiler, B. Hopley, A. Marshall, and S. Phelps. 1992. Yakima hatchery experimental design. Semi-annual progress report to Bonneville Power Administration, Project 89-082, Contract DE-B179-89BP00102.

Busack, C., S. Schroder, and C. Knudsen. 2002. YKFP Spring Chinook Domestication/Monitoring Designs. *In* Yakima/Klickitat Fisheries Project Genetic Studies. BPA Annual Report 2001.

Busack, C., S.L. Schroder, T. Pearsons, C.M. Knudsen. 2004. Further Development of Spring Chinook Domestication Monitoring Plan. *In* Yakima/Klickitat Fisheries Project Genetic Studies. BPA Annual Report 2003.

Busack, C., B. Watson, T. Pearsons, C. Knudsen, S. Phelps and M. Johnston. 1997. Spring Chinook Supplementation Monitoring Plan. Report to Bonneville Power Administration, Publ. No. DOE/BP 64878-1. 185 pp.

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transaction of the American Fisheries Society 115:726-735.

Fleming, I.A., and M.R. Gross. 1990. Latitudinal clines: A trade-off between egg number and size in Pacific salmon. Ecology 71:1-11.

Gallinat, M., J. Bumgarner, L. Ross, and M. Varney. 2001. Tucannon River spring chinook salmon hatchery evaluation Program, 2000 Annual Report No. FPA01-05. 44 pp.

Hard, J. 1995. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. Amer. Fish. Soc. Sym. 15:212-225.

Healey, M., and R. Heard. 1985. Inter- and intra-population variation in the fecundity of chinook salmon (*Oncorhynchus tshawytscha*) and its relevance to life history theory. Can. J. Fish Aquat. Sci. 41:476-483.

Heath, D., C. Fox, and J. Heath. 1999. Maternal effects on offspring size: Variation through early development of chinook salmon. Evolution 53(3):1605-1611.

Heath, D., C. Bryden, J. Shrimpton, G. Iwama,J. Kelly, and J. Heath. 2002. Relationships between heterozygosity, allelic distance ($d^2$), and reproductive traits in chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Fish. Aquat. Sci. 59: 77–84.

Heath, D., J. Heath, C. Bryden, R. Johnson, and C. Fox. 2003. Rapid evolution of egg size in captive salmon. Science 299:1738-1740.

Hendry, A.P., J.E.Hensleigh, and R.R. Reisenbichler. 1998. Incubation temperature, developmental biology, and the divergence of sockeye salmon (*Oncorhynchus nerka*) within Lake Washington. Can. J. Fish. Aquat. Sci. 55:1387-1394.

Hendry, A., T. Day, and A. Cooper. 2001. Optimal size and number of propagules: Allowance for discrete stages and effects of maternal size on reproductive output and offspring fitness. American Naturalist 157:387-407.

Iwamoto, R., B. Alexander, and W. Hershberger. 1984. Genotypic and environmental effects on the incidence of sexual precocity in coho salmon (*Oncorhynchus kisutch*). Aquaculture 43:105-121.

Jonsson, N., B. Jonsson, and I. Fleming. 1996. Does early growth cause a phenotypically plastic response in egg production of Atlantic salmon? Functional Ecology 10:89-96.

Kinnison, M., M. Unwin, W. Hershberger, and T. Quinn. 1998. Egg size, fecundity and early development rate of two New Zealand chinook salmon (*Oncorhynchus tshawytscha*) populations, with a comparison to their ancestral Sacremento River population. Can. J. Fish. Aquat. Sci. 55:1946-1953.

Kinnison, M., M. Unwin, A. Hendry, and T. Quinn. 2001. Migratory costs and the evolution of egg size and number in introduced and indigenous salmon populations. Evolution 55(8):1656-1667.

Knudsen, C.M, S.L. Schroder, J. Rau, C. Strom, M. Johnston and M. Hammlin. 2002a. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild spring chinook: Spawner traits. Pages 4-39 in *Reproductive Ecology of*

*Yakima River hatchery and wild spring chinook and Juvenile-to-Adult PIT Tag Retention Study*, ed. by C.M. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2001.

Knudsen, C.M, S.L. Schroder, J. Rau, C. Strom, and M. Hammlin. 2002b. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild spring chinook: Gametic and juvenile traits. Pages 41-61 in *Reproductive Ecology of Yakima River hatchery and wild spring chinook and Juvenile-to-Adult PIT Tag Retention Study*, ed. by C.M. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2001.

Knudsen, C.M., S.L. Schroder, T. Pearsons, J. A Rau, A. L. Fritts, and Strom, C.R. 2003. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild Spring chinook: Gametic and juvenile traits. Pages 37-62 in *Reproductive Ecology of Yakima River hatchery and wild spring chinook*, ed. by C. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2002.

Knudsen, C.M., S.L. Schroder, M.V. Johnston, T.N. Pearsons, J. A Rau, C.R. Strom, and M.L. Hamlin. 2004. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild Spring chinook: Spawner traits. In *Reproductive Ecology of Yakima River hatchery and wild spring chinook*, ed. by C. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2003.

Larsen, D.A., B.R. Beckman, K.A. Cooper, D. Barrett, M. Johnston, P. Swanson and W.W. Dickhoff. 2004. Assessment of high rates of precocious male maturation in a spring chinook salmon supplementation hatchery program. Transactions of the American Fisheries Society 133:98–120.

Leider, S.A., P. Hulett, J.J. Loch, and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the adult return stage. Aquaculture 88:239-252.

Pearsons, T. N., B. B. Ben-James, C. L. Johnson, A. L. Fritts and G. M.Temple. 2003. Precocially mature hatchery and wild spring chinook salmon on the spawning grounds. In *Spring chinook salmon interactions indices and residual/precocial monitoring in the Upper Yakima Basin*, BPA Annual Report 2002.

Pearsons, T. N., C.L. Johnson, B. B. Ben-James, and G. M.Temple. 2003. Precocially mature hatchery and wild spring chinook salmon on the spawning grounds. In *Spring chinook salmon interactions indices and residual/precocial monitoring in the Upper Yakima Basin*, BPA Annual Report 2003.

Pianka, E. 1976. Natural selection of reproductive tactics. Amer. Zool. 16:775-784.

Quinn, T.P., A.P. Henry, and L.A. Wetzel. 1995. The influence of life history trade-offs

and the size of incubation gravels on egg variation in sockeye salmon (*Oncorhynchus nerka*). Oikos 74:425-438.

Quinn, T., M. Kinnison, and M. Unwin. 2001. Evolution of chinook salmon (*Oncorhynchus tshawytscha*) populations in New Zealand:pattern, rate, and process. Genetica 112-113:493-513.

Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, (*Salmo garidneri*). Journal of the Fisheries Research Board of Canada 34:123-128.

Riddell, B.E. 1986. Assessment of selective fishing on age at maturation in Atlantic salmon (*Salmo salar*): A genetic perspective, p. 102-109. In D.J. Meerburg [ed.] Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Sampsel, M., and D. Fast. 2001. Monitoring And Evaluation. Yakima/Klickitat Fisheries Project Final Report 2000. BPA Report DOE/BP-00000650-1.

Schroder, S.L., C.M. Knudsen, B.A. Berijikian, and E.P. Tezak. *In press*. Gamete quality and pre-emergent performance of offspring produced from captively reared and wild coho salmon. *In* P. Swanson, editor, *Captive Broodstock Annual Report*. Report to Bonneville Power Administration, Contract DE-AI79-93BP55064. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112.)

Schroder, S.L., C.M. Knudsen, B. Watson, T. Pearsons, and J. Rau. 2002. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2001 Annual Report.

Schroder, S.L., C.M. Knudsen, B. Watson, T. Pearsons, and J. Rau. 2003. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2002 Annual Report.

Taylor, E. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

Thorpe, J.E., and M.S. Miles, and D.S. Keay. 1984. Developmental rate, fecundity and egg size in Atlantic salmon, *Salmo salar* L. Aquaculture 43:289-305.

Unwin, M.J. and G.J. Glova. 1997. Changes in life history parameters in a naturally spawning population of chinook salmon (*Oncorhynchus tshawytscha*) associated with releases of hatchery-reared fish. Can. J. Fish. Aquat. Sci. 54(6): 1235-1245.

Zar, J.H. 1984. Biostatistical Analysis. Prentice Hall, Inc., Englewood Cliffs, NJ.

# Chapter 3

# Spawner and Redd Characteristics of Wild- and Hatchery-Origin Upper Yakima River Spring Chinook

Prepared by:

Curtis M. Knudsen[1], Brenda L. Ben–James[2],

Todd N. Pearsons[3] and Steve L. Schroder[4]

[1] Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

[2] Cascade Aquatics, Ellensburg, WA 98926

[3] Ecological Interactions Team, Washington Department of Fish and Wildlife, 201 N. Pearl Street, Ellensburg, WA 98926

[4] Washington Department of Fish and Wildlife, 600 Capitol Way North Olympia, WA 98501

## Abstract

In 2003, we measured redds of naturally spawning upper Yakima River hatchery and wild females constructed *in situ* and compared them to redds constructed in the CESRF spawning channel. Redd measurements included water depth, velocity and substrate characteristics; and redd width and length. In-river redds were snorkel surveyed 3 to 4 days per week between September 19 and October 6 and were associated with females of known origin by the presence (wild) or absence (hatchery) of the female's adipose fin. Channel females were individually identified by number tags and observed constructing redds. Redd measurements were taken once females were no longer present on the redd.

Spawning densities in the In-river study reach were low in 2003 resulting in a only total of 24 In-river redds being monitored. Of those, 13 were unambiguously identified as hatchery- and 4 as wild-origin. There were 12 hatchery- and 12 wild-origin redds constructed in the spawning channel. There was no significant difference in fork lengths of naturally spawning hatchery and wild females. In comparisons of redd width and length dimensions, water depths, velocities and substrate parameters within the Channel, there were no significant hatchery or wild differences. Because the small In-river wild-origin sample size resulted in low statistical power, we made no statistical comparisons between In-river hatchery and wild origin redds. In only one of 37 tests were redd measurements significantly correlated with female fork length and in that case female length explained only 14% of the total variation in apex water depth. This was similar to 2002 results. We found that the CESRF experimental spawning channel redds were characterized by lower velocity and shallower spawning habitat than that preferred by In-river spawning females. There were significant differences between Channel and In-river redds in almost all width, length, velocity and depth measurements.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

# Introduction

Within the area of Reproductive Success, a critical concern is the *in situ* reproductive performance of naturally spawning hatchery returns compared to their wild counterparts. We are interested in whether hatchery origin females have similar spatial and temporal distributions within a given river reach, take the same time to construct and guard individual redds, utilize similar types of spawning habitat, and construct comparably sized redds compared to wild origin females. This requires intensive monitoring of in-river spawners that links the origin of females with their respective redds. Naturally spawning hatchery fish have been shown to be less reproductively successful then wild fish (Resenbichler and McIntyre 1977; Chilcote et al. 1986; van den Berghe and Gross 1989; Leider et al. 1990) particularly in populations that have experienced multiple years of domestication (see review in Schroder et al. 2002).

In this chapter we make comparisons between redds of naturally spawning hatchery and wild origin females constructed in two sites: the upper Yakima River (In-river) and the experimental spawning channel (Channel) located at the Cle Elum Supplementation and Research Facility (CESRF). Our first objective was to compare the characteristics of hatchery and wild redds constructed within each site: In-river and Channel. We then compared redds across the two sites to determine if the females spawning in the channel select habitat and produce redds comparable to those constructed in-river. Finally, we estimated whether female size (fork length) and redd measurements are correlated and can explain significant variation in redd characteristics.

## Methods and Materials

The *in situ* study area is located in the upper Yakima River beginning just downstream of Easton Dam and extending downstream to the Yakima/Klickitat Fishery Project's Easton spring chinook acclimation site. Redds were sampled by snorkeling 3 to 4 days per week between September 19 and October 6, 2003. Females were identified to origin based in the presence (wild) or absence (hatchery) of their adipose fin. All spring chinook released from the CESRF are adipose fin clipped. During each survey a female's length was estimated visually.

After spawning was completed and redd construction was finished, a suite of characters were collected (Table 1; Fig. 1) characterizing the physical dimensions (maximum width and length, bowl length, and tail length), water depth and velocity (at corresponding points length measurements were taken from). A visual assessment of substrate characteristics were made by estimating the percent sand, gravel, cobble and boulder. Redd habitat types were given an ordinal score: riffle=1, pool=2 and glide=3. All water velocity measurements were taken at 0.6 depth with additional surface and bottom velocities measured at the front and back of the tail. The distance to nearest contemporaneous redd was also measured. That is, the distance to the nearest redd

occupied by an actively digging or guarding female. A total of 14 hatchery- and 4 wild-origin In-river redds were unambiguously identified and measured in 2003. Spawner density was much lower in this reach of the river than in typical years resulting in the low number of wild origin redds surveyed. Redds in the CESRF spawning channel were surveyed from October 13 to 26. As Channel females spawned they were individually identified by a numbered Peterson disk tag and associated with a specific redd based on visual observations (Schroder et al. 2004). There were 12 hatchery origin and 12 wild origin channel redds measured.

The percentage substrate variables were arc sin transformed prior to analyses. The SYSTAT 8.0 software package was used to perform all regression and ANOVAs (SPSS 1998).

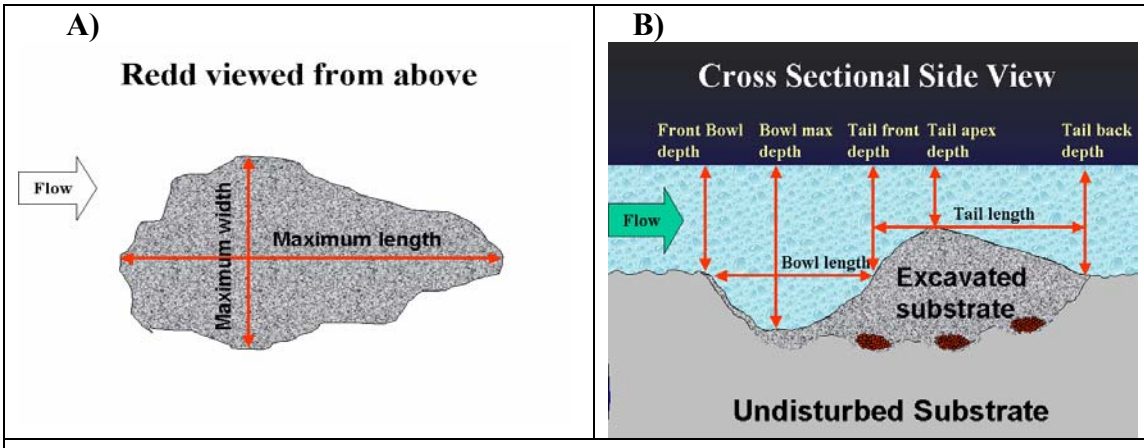



**Figure 3. A schematic of a redd as viewed from above A) and in cross section B) showing the parameters measured. Water velocities were measured at each point a depth measurement was collected.**

Table 1. Redd measurements and definitions.

| Measurement | Description |
|---|---|
| Bowl front depth | Water depth (*m*) from the surface to the substrate just upstream of the bowl |
| Front bowl velocity | Water velocity (*m*/sec) at 0.6 depth taken at the same point as "Bowl front depth" |
| Maximum bowl depth | The maximum water depth (*m*) from the surface to the bottom of the bowl |
| Tail apex depth | Water depth (*m*) from the top of the mound formed by the redd tailings |
| Front tail depth | Water depth (*m*) from the back of the bowl/ beginning of the tail |
| Tail surface velocity | Water velocity (*m*/sec) at the surface at the "Front tail" point |
| Tail bottom velocity | Water velocity (*m*/sec) on the bottom at the "Front tail" point |
| Front tail velocity | Water velocity (*m*/sec) at 0.6 depth taken at the same point |
| Left redd velocity | Water velocity (*m*/sec) at 0.6 depth taken at the same point |

| Table 1. cont'd. Redd measurements and definitions. | |
|---|---|
| Measurement | Description |
| Back tail velocity | Water velocity (*m*/sec) at 0.6 depth taken at the same point |
| Redd max. length | Maximum length (*m*) |
| Redd max. width | Maximum width (*m*) |
| Bowl length | Length (*m*) |
| Tail length | Length (*m*) |
| Bowl % sand | Visual estimate of the percentage of substrate made up of sand |
| Bowl % gravel | Visual estimate of the percentage of substrate made up of gravel |
| Bowl % cobble | Visual estimate of the percentage of substrate made up of cobble |
| Bowl % boulder | Visual estimate of the percentage of substrate made up of boulders |
| Tail % sand | Visual estimate of the percentage of substrate made up of sand |
| Tail % gravel | Visual estimate of the percentage of substrate made up of gravel |
| Tail % cobble | Visual estimate of the percentage of substrate made up of cobble |
| Tail % boulder | Visual estimate of the percentage of substrate made up of boulders |

## Results

For the in-river surveys, we averaged the visual length estimates for a female unambiguously identified as either of hatchery or wild origin and used that average in the analyses below. Mean in-river hatchery and wild female fork lengths were 75 and 68 *cm*, respectively. Spawning channel mean fork lengths were 76 and 77 cm for hatchery and wild females, respectively (Table 2). Wild female lengths were not significantly different than hatchery females nor were the in-river lengths different from the channel (Table 3).

Table 2. Mean fork length of Hatchery and Wild origin females based on multiple visual observations during snorkel surveys. In-river lengths are estimated visually *in situ* and channel lengths are taken from fish prior to placement into the channel.

| Site | Origin | Mean (*cm*) | sd | n | cv |
|---|---|---|---|---|---|
| In-river | Hatchery | 74.8 | 8.5 | 14 | 11.4% |
| | Wild | 68.2 | 7.7 | 4 | 11.2% |
| Spawning channel | Hatchery | 76.1 | 7.5 | 12 | 9.8% |
| | Wild | 77.2 | 7.9 | 12 | 10.3% |

| Table 3. Two-way ANOVA results comparing female fork lengths by Origin (Hatchery/Wild) and Site (In-river/Spawning channel). | | | | | |
|---|---|---|---|---|---|
| Effect | *SSQ* | *df* | Mean-sq | *F*-ratio | *p*-value |
| Origin | 6321.6 | 1 | 6321.6 | 0.990 | 0.326 |
| Site | 21365.3 | 1 | 21365.3 | 3.318 | 0.075 |
| Origin*Site | 11796.7 | 1 | 11796.7 | 1.848 | 0.182 |
| Error | 242531.0 | 38 | 6382.4 | | |

We made comparisons between females of hatchery- and wild-origin redd characters in the Channel (Appendix 1) and in no case was there a significant difference. Only water velocity at the front of the bowl ($p$=0.06) and on the right side ($p$=0.08) were close to being statistically significant, while the remaining ANOVAs had $p$>0.26. We did not compare the substrate composition measurements or distance to nearest redd data. Due to the small In-river wild-origin sample of 4 redds, we did not make statistical comparisons of hatchery and wild redds. Redd character means, standard deviations and sample size of In-river and Channel samples by origin are given in Appendix 2.

Females spawning in the river utilized areas with much higher water velocities and depth than in the spawning channel. This is shown by the clustering of Channel points in the lower left corner of Figure 2 and the distribution of In-river points in the upper right portion of the figure. The channel females did not make a choice between habitat types, however. Rather, the spawning channel did not provide areas of spawning substrate with high water velocity and depth. In the channel, high water velocities (>0.7 *m*/sec) were restricted to narrow chutes where water dropped from one channel section into the next. These areas were armored with large (6"-18" diameter) rock to protect it from scouring, making it unsuitable for spawning. Channel females did use the areas just downstream from the chutes, but velocities had dropped below 0.7 *m*/sec by then. The differences in water velocity and depth influence other redd characteristics such as redd size, particularly length, since the distance substrate will travel downstream during excavation is determined by water velocity.

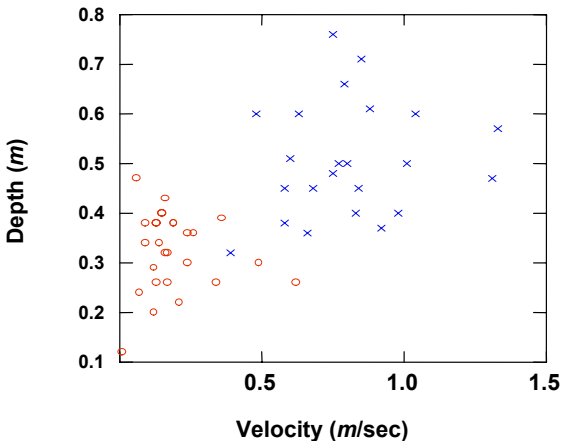



**Figure 2. Scatter plot of water depth and water velocity immediately in front of the bowl for In-river (x) and Channel (o) redds.**

An additional difference between the Channel and the In-river spawning habitat is that the Channel is lined with a semi-permeable geotextile barrier with the spawning substrate placed on top to a depth of 2-3 feet. The geotextile barrier limits the depth to which females can dig and we did observe females digging redds that exposed the barrier, particularly at the upper end of the Channel where substrate depth is lowest. These females would likely have dug deeper redds had the barrier not prevented it.

We pooled the hatchery and wild origin samples within sites and examined the correlation of female fork length and redd characteristics. The results of these linear regressions are in given in Table 4. Female length was found to explain significant variation in only one of 37 regression analyses, tail apex water depth ($p$=0.04) in the Channel. Apex depth was negatively correlated with female length (larger females created higher mounds resulting in shallower depths at the apex) and explained 14% of the total variation in apex depth. This measurement was not surveyed in the In-river samples.

Table 4. Linear regression results of female fork length versus the listed redd character by Site (In-river/Channel).

| Redd Character | Origin | N | Adj. $R^2$ | Constant | Coefficient | Regression $p$-value |
|---|---|---|---|---|---|---|
| Habitat type | In-river | 17 | 0.000 | 692.6 | 19.3 | 0.617 |
| | Channel | 24 | 0.000 | 642.0 | 43.6 | 0.350 |
| Bowl front depth | In-river | 18 | 0.000 | 778.3 | -88.3 | 0.626 |
| | Channel | 24 | 0.000 | 68.2 | 24.0 | 0.910 |
| Bowl front velocity | In-river | 18 | 0.000 | 661.2 | 95.2 | 0.383 |
| | Channel | 24 | 0.000 | 28.4 | -28.8 | 0.809 |
| Maximum bowl depth | In-river | 18 | 0.000 | 805.4 | -127.6 | 0.585 |
| | Channel | 24 | 0.000 | 712.9 | 149.4 | 0.518 |
| Tail apex depth | In-river | 1 | | | | |
| | Channel | 24 | 0.136 | 889.7 | -489.7 | *0.043 |
| Front tail depth | In-river | 18 | 0.000 | 775.7 | -80.9 | 0.697 |
| | Channel | 24 | 0.000 | 800.3 | -113.4 | 0.697 |
| Tail surface velocity | In-river | 18 | 0.054 | 598.3 | 149.4 | 0.180 |
| | Channel | 24 | 0.000 | 769.6 | -10.8 | 0.896 |
| Front tail velocity | In-river | 18 | 0.000 | 641.7 | 124.8 | 0.356 |
| | Channel | 24 | 0.000 | 772.8 | -28.0 | 0.806 |
| Left redd velocity | In-river | 18 | 0.000 | 711.7 | 25.3 | 0.831 |
| | Channel | 24 | 0.000 | 769.6 | -32.0 | 0.836 |
| Left depth | In-river | 18 | 0.000 | 700.4 | 73.6 | 0.657 |
| | Channel | 24 | 0.000 | 749.6 | 67.0 | 0.633 |
| Right redd velocity | In-river | 18 | 0.012 | 831.0 | -133.0 | 0.287 |
| | Channel | 24 | 0.000 | 769.0 | -16.6 | 0.902 |
| Right depth | In-river | 18 | 0.000 | 751.6 | -38.4 | 0.871 |
| | Channel | 24 | 0.000 | 795.2 | -104.6 | 0.490 |

| Table 4. cont'd. Linear regression results of female fork length versus the listed redd character by Site (In-river/Channel). | | | | | | |
|---|---|---|---|---|---|---|
| Redd Character | Origin | N | Adj. $R^2$ | Constant | Coefficient | Regression *p*-value |
| Back tail depth | In-river | 18 | 0.002 | 810.1 | -187.5 | 0.324 |
| | Channel | 24 | 0.000 | 799.8 | -125.0 | 0.660 |
| Back tail velocity | In-river | 17 | 0.000 | 658.6 | 86.9 | 0.547 |
| | Channel | 24 | 0.016 | 803.1 | -139.7 | 0.253 |
| Redd max. length | In-river | 18 | 0.000 | 694.7 | 7.1 | 0.661 |
| | Channel | 24 | 0.043 | 698.8 | 21.9 | 0.168 |
| Redd max. width | In-river | 18 | 0.147 | 893.7 | -49.1 | 0.065 |
| | Channel | 24 | 0.000 | 751.3 | 10.8 | 0.870 |
| Bowl length | In-river | 18 | 0.000 | 761.0 | -19.3 | 0.669 |
| | Channel | 24 | 0.000 | 738.9 | 19.8 | 0.509 |
| Tail length | In-river | 18 | 0.000 | 705.6 | 7.1 | 0.707 |
| | Channel | 24 | 0.053 | 710.4 | 33.0 | 0.145 |
| Distance nearest redd | In-river | 18 | 0.000 | 726.1 | 0.6 | 0.753 |
| | Channel | 24 | 0.011 | 779.7 | -5.5 | 0.275 |

## Discussion

We found no differences in redds constructed by hatchery- and wild-origin females in 2003, whether in the Channel or In-river samples. These results agree with those from In-river redd surveys in 2002 (Knudsen et al. 2003).

Although female lengths were spread over a relatively wide 30 *cm* (60 to 90 *cm* covering both age-4 and -5's), no redd characteristics were found to be strongly correlated with female length. In the few measurements that were correlated, female length explained no more than 14% of the total variation. We also found no strong correlations between female length and In-river redd characteristics in 2002 (Knudsen et al. 2003). The In-river hatchery origin females (ages 4 and 5 combined) were larger than wild females on average, although this was not statistically significant. In the naturally spawning upper Yakima River population, the proportion of age-5 hatchery (24%) origin fish was 3 times greater than age-5 wild (8%) origin fish (Knudsen et al. 2004). Thus, it is understandable that the mean length of In-river hatchery females, with a higher proportion of age-5's, would be greater than the mean wild female length. Female lengths were more similar in the Channel because they were selected to be comparable in size, although we did not attempt to size-match every fish.

In the present study, we found that spawning channel redds were characterized by velocities and depths that were significantly lower than those preferred in the In-river survey area. This was because the Channel did not have suitable spawning substrate with

the higher velocities and depths, not because of female preferences. However, the channel did provide spawning and incubation habitat that produced egg-to-fry survivals of 50% or greater (Schroder and Knudsen, unpublished data). The lower water velocity and depth of the channel certainly influenced other redd characteristics such as maximum redd length and width and perhaps bowl depth to a lesser degree.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

## Acknowledgements

Our thanks to the in-river redd survey crew of Devona Ensmenger, Corene Luton, Keith Pitts, Tyler Forman, and David Childs, as well as, Christopher Johnson and Timothy Webster for their help in surveying spawning channel redds. We also thank David Byrnes, Bonneville Power Administration, for continued support and help in securing and administering funding for this work.

## References

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transaction of the American Fisheries Society 115:726-735.

Hard, J. 1995. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. Amer. Fish. Soc. Sym. 15:212-225.

Knudsen, C.M., S.L. Schroder, M.V. Johnston, T.N. Pearsons, J. A Rau, C.R. Strom, and M.L. Hamlin. 2004. Monitoring phenotypic and demographic traits of Yakima River hatchery and wild Spring chinook: Spawner traits. In *Reproductive Ecology of Yakima River hatchery and wild spring chinook*, ed. by C. Knudsen. Annual Report to Washington Department of Fish and Wildlife 2003.

Leider, S.A., P. Hulett, J.J. Loch, and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the adult return stage. Aquaculture 88:239-252.

Resenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, (*Salmo garidneri*). Journal of the Fisheries Research Board of Canada 34:123-128.

Schroder, S.L., C.M. Knudsen, B. Watson, T. Pearsons, and J. Rau. 2002. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2001 Annual Report.

Schroder, S.L., C.M. Knudsen, B. Watson, T. Pearsons, and J. Rau. 2004. Comparing the reproductive success of Yakima River hatchery and wild spring chinook. YKFP 2003 Annual Report.

SPSS. 1998. SYSTAT 8.0 Statistics, SPSS, Inc. Chicago, IL

Taylor, E. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

van den Berghe, E.P., and M.R. Gross. 1989. Natural selection resulting from female breeding competition in a Pacific salmon (Coho: *Oncorhynchus kisutch*). Evolution 43: 125-140.

# Appendix 1.

| Appendix 1. One-way ANOVA results estimating Origin (Hatchery vs Wild) effects on CESRF spawning channel redd measurement distribution in 2003. | | | | | |
|---|---|---|---|---|---|
| Source/Measurement | *SSq* | *df* | *MSq* | *F*-ratio | *P*-value |
| Habitat type | 0.01 | 1 | 0.01 | 0.08 | 0.775 |
| Error | 2.73 | 22 | 0.12 | | |
| Front bowl depth | <0.01 | 1 | <0.01 | 0.01 | 0.938 |
| Error | 0.13 | 22 | 0.01 | | |
| Front bowl velocity | 0.07 | 1 | 0.07 | 4.03 | 0.057 |
| Error | 0.36 | 22 | 0.02 | | |
| Bowl depth | <0.01 | 1 | <0.01 | 0.52 | 0.479 |
| Error | 0.11 | 22 | 0.01 | | |
| Front tail depth | 0.01 | 1 | 0.01 | 0.86 | 0.355 |
| Error | 1.66 | 101 | 0.02 | | |
| Tail apex depth | 0.01 | 1 | 0.01 | 1.33 | 0.262 |
| Error | 0.09 | 22 | <0.01 | | |
| Tail front depth | <0.01 | 1 | <0.01 | 0.02 | 0.888 |
| Error | 0.07 | 22 | <0.01 | | |
| Front tail velocity | 0.03 | 1 | 0.03 | 1.36 | 0.255 |
| Error | 0.44 | 22 | 0.02 | | |
| Left redd depth | <0.01 | 1 | <0.01 | 0.19 | 0.669 |
| Error | 0.28 | 22 | 0.01 | | |
| Left redd velocity | 0.03 | 1 | 0.03 | 3.30 | 0.083 |
| Error | 0.22 | 22 | 0.01 | | |
| Right redd depth | 0.02 | 1 | 0.02 | 1.33 | 0.260 |
| Error | 0.25 | 22 | 0.01 | | |
| Right redd velocity | 0.01 | 1 | 0.01 | 0.40 | 0.532 |
| Error | 0.33 | 22 | 0.33 | | |
| Back tail depth | <0.01 | 1 | <0.01 | 0.92 | 0.347 |
| Error | 0.07 | 22 | <0.01 | | |
| Back tail velocity | <0.01 | 1 | <0.01 | 0.01 | 0.940 |
| Error | 0.40 | 22 | 0.02 | | |
| Maximum redd length | 0.87 | 1 | 0.87 | 0.86 | 0.365 |
| Error | 22.38 | 22 | 1.02 | | |
| Maximum redd width | 0.02 | 1 | 0.02 | 0.34 | 0.565 |
| Error | 1.40 | 22 | 0.06 | | |
| Bowl length | 0.35 | 1 | 0.35 | 1.20 | 0.284 |
| Error | 6.40 | 22 | 0.29 | | |
| Tail length | 0.12 | 1 | 0.12 | 0.23 | 0.638 |
| Error | 11.26 | 22 | 0.51 | | |
| Distance left bank | 1.91 | 1 | 1.91 | 0.82 | 0.375 |
| Error | 51.32 | 22 | 2.33 | | |
| Distance right bank | 2.12 | 1 | 2.12 | 1.04 | 0.320 |
| Error | 45.00 | 22 | 2.05 | | |
| Bowl % gravel | 84.38 | 1 | 84.38 | 1.08 | 0.309 |
| Error | 1714.58 | 22 | 77.94 | | |
| Tail % gravel | 37.50 | 1 | 37.50 | 0.54 | 0.470 |
| Error | 1525.00 | 22 | 69.32 | | |

# Appendix 2.

| Appendix 2. Mean, standard deviations (sd) and sample size (n) for 2003 redd characters by Site (In-river/Channel) and Origin (Hatchery/Wild). | | | | | |
|---|---|---|---|---|---|
| Redd Character | Sample site | Origin | Mean | sd | n |
| Habitat type | Channel | Hatchery | 2.88 | 0.31 | 12 |
| | | Wild | 2.83 | 0.39 | 12 |
| | In-river | Hatchery | 2.69 | 0.48 | 13 |
| | | Wild | 2.00 | 0.0 | 4 |
| Bowl front depth | Channel | Hatchery | 0.32 | 0.10 | 12 |
| | | Wild | 0.31 | 0.06 | 12 |
| | In-river | Hatchery | 0.50 | 0.12 | 14 |
| | | Wild | 0.53 | 0.12 | 4 |
| Bowl front velocity | Channel | Hatchery | 0.15 | 0.09 | 12 |
| | | Wild | 0.25 | 0.16 | 12 |
| | In-river | Hatchery | 0.77 | 0.22 | 14 |
| | | Wild | 0.74 | 0.12 | 4 |
| Maximum bowl depth | Channel | Hatchery | 0.37 | 0.08 | 12 |
| | | Wild | 0.35 | 0.06 | 12 |
| | In-river | Hatchery | 0.56 | 0.10 | 14 |
| | | Wild | 0.57 | 0.10 | 4 |
| Tail apex depth | Channel | Hatchery | 0.27 | 0.07 | 12 |
| | | Wild | 0.24 | 0.06 | 12 |
| | In-river | Hatchery | 0.18 | 0.0 | 1 |
| | | Wild | | | 0 |
| Front tail depth | Channel | Hatchery | 0.30 | 0.06 | 12 |
| | | Wild | 0.30 | 0.05 | 12 |
| | In-river | Hatchery | 0.53 | 0.11 | 14 |
| | | Wild | 0.50 | 0.09 | 4 |
| Tail surface velocity | Channel | Hatchery | 0.25 | 0.12 | 12 |
| | | Wild | 0.34 | 0.25 | 12 |
| | In-river | Hatchery | 0.88 | 0.19 | 14 |
| | | Wild | 0.75 | 0.23 | 4 |
| Front tail velocity | Channel | Hatchery | 0.19 | 0.10 | 12 |
| | | Wild | 0.26 | 0.18 | 12 |
| | In-river | Hatchery | 0.73 | 0.14 | 14 |
| | | Wild | 0.75 | 0.23 | 4 |
| Left redd velocity | Channel | Hatchery | 0.06 | 0.10 | 12 |
| | | Wild | 0.14 | 0.10 | 12 |
| | In-river | Hatchery | 0.86 | 0.21 | 14 |
| | | Wild | 0.90 | 0.09 | 4 |
| Left depth | Channel | Hatchery | 0.25 | 0.14 | 12 |
| | | Wild | 0.23 | 0.08 | 12 |
| | In-river | Hatchery | 0.47 | 0.13 | 14 |
| | | Wild | 0.39 | 0.14 | 4 |
| Right redd velocity | Channel | Hatchery | 0.17 | 0.13 | 12 |
| | | Wild | 0.14 | 0.12 | 12 |
| | In-river | Hatchery | 0.71 | 0.17 | 14 |
| | | Wild | 0.82 | 0.19 | 4 |

Appendix 2. cont'd. Mean, standard deviations (sd) and sample size (n) for 2003 redd characters by Site (In-river/Channel) and Origin (Hatchery/Wild).

| Redd Character | Sample site | Origin | Mean | sd | n |
|---|---|---|---|---|---|
| Right depth | Channel | Hatchery | 0.30 | 0.11 | 12 |
| | | Wild | 0.25 | 0.10 | 12 |
| | In-river | Hatchery | 0.47 | 0.10 | 14 |
| | | Wild | 0.45 | 0.08 | 4 |
| Back tail depth | Channel | Hatchery | 0.28 | 0.06 | 12 |
| | | Wild | 0.26 | 0.06 | 12 |
| | In-river | Hatchery | 0.37 | 0.10 | 13 |
| | | Wild | 0.37 | 0.16 | 4 |
| Back tail velocity | Channel | Hatchery | 0.27 | 0.14 | 12 |
| | | Wild | 0.26 | 0.13 | 12 |
| | In-river | Hatchery | 0.93 | 0.15 | 13 |
| | | Wild | 1.03 | 0.11 | 4 |
| Redd max. length | Channel | Hatchery | 3.28 | 1.26 | 12 |
| | | Wild | 2.90 | 0.66 | 12 |
| | In-river | Hatchery | 5.68 | 1.43 | 14 |
| | | Wild | 4.88 | 0.90 | 4 |
| Redd max. width | Channel | Hatchery | 1.38 | 0.28 | 12 |
| | | Wild | 1.44 | 0.22 | 12 |
| | In-river | Hatchery | 3.26 | 0.83 | 14 |
| | | Wild | 3.25 | 0.62 | 4 |
| Bowl length | Channel | Hatchery | 1.51 | 0.70 | 12 |
| | | Wild | 1.27 | 0.31 | 12 |
| | In-river | Hatchery | 1.44 | 0.46 | 14 |
| | | Wild | 1.35 | 0.62 | 4 |
| Tail length | Channel | Hatchery | 1.77 | 0.78 | 12 |
| | | Wild | 1.63 | 0.64 | 12 |
| | In-river | Hatchery | 4.09 | 1.27 | 14 |
| | | Wild | 3.53 | 0.59 | 4 |
| Distance nearest redd | Channel | Hatchery | 2.55 | 3.04 | 12 |
| | | Wild | 2.28 | 3.46 | 12 |
| | In-river | Hatchery | 15.86 | 12.20 | 14 |
| | | Wild | 3.88 | 4.63 | 4 |
| Distance to left bank | Channel | Hatchery | 1.48 | 1.49 | 12 |
| | | Wild | 2.04 | 1.56 | 12 |
| | In-river | Hatchery | 15.21 | 6.79 | 14 |
| | | Wild | 21.43 | 3.09 | 4 |
| Distance to right bank | Channel | Hatchery | 2.35 | 1.33 | 12 |
| | | Wild | 1.76 | 1.53 | 12 |
| | In-river | Hatchery | 15.46 | 9.46 | 14 |
| | | Wild | 13.90 | 2.18 | 4 |
| Bowl % sand | Channel | Hatchery | 0.0 | 0.0 | 12 |
| | | Wild | 0.0 | 0.0 | 12 |
| | In-river | Hatchery | 20.36 | 7.46 | 14 |
| | | Wild | 25.00 | 10.80 | 4 |
| Bowl % gravel | Channel | Hatchery | 17.08 | 8.38 | 12 |
| | | Wild | 20.83 | 9.25 | 12 |
| | In-river | Hatchery | 23.93 | 8.81 | 14 |
| | | Wild | 17.50 | 6.45 | 4 |

| Appendix 2. cont'd. Mean, standard deviations (sd) and sample size (n) for 2003 redd characters by Site (In-river/Channel) and Origin (Hatchery/Wild). | | | | | |
|---|---|---|---|---|---|
| Redd Character | Sample site | Origin | Mean | sd | n |
| Bowl % gravel | Channel | Hatchery | 17.08 | 8.38 | 12 |
| | | Wild | 20.83 | 9.25 | 12 |
| | In-river | Hatchery | 23.93 | 8.81 | 14 |
| | | Wild | 17.50 | 6.45 | 4 |
| Bowl % cobble | Channel | Hatchery | 82.92 | 8.38 | 12 |
| | | Wild | 79.17 | 9.25 | 12 |
| | In-river | Hatchery | 25.36 | 11.84 | 14 |
| | | Wild | 15.00 | 10.00 | 4 |
| Bowl % boulder | Channel | Hatchery | 0.0 | 0.0 | 12 |
| | | Wild | 0.0 | 0.0 | 12 |
| | In-river | Hatchery | 30.36 | 13.08 | 14 |
| | | Wild | 42.50 | 5.00 | 4 |
| Tail % sand | Channel | Hatchery | 0.0 | 0.0 | 12 |
| | | Wild | 0.0 | 0.0 | 12 |
| | In-river | Hatchery | 13.93 | 8.81 | 14 |
| | | Wild | 17.50 | 9.57 | 4 |
| Tail % gravel | Channel | Hatchery | 17.50 | 7.54 | 12 |
| | | Wild | 15.00 | 9.05 | 12 |
| | In-river | Hatchery | 16.43 | 10.82 | 14 |
| | | Wild | 12.50 | 5.00 | 4 |
| Tail % cobble | Channel | Hatchery | 82.50 | 7.54 | 12 |
| | | Wild | 85.00 | 7.54 | 12 |
| | In-river | Hatchery | 42.86 | 15.53 | 14 |
| | | Wild | 32.50 | 12.58 | 4 |
| Tail % boulder | Channel | Hatchery | 0.0 | 0.0 | 12 |
| | | Wild | 0.0 | 0.0 | 12 |
| | In-river | Hatchery | 26.79 | 14.62 | 14 |
| | | Wild | 37.50 | 15.00 | 4 |

# Appendix 3

Appendix 3. One-way ANOVA results estimating Site effects (In-river vs. Spawning channel) on redd measurement distribution in 2003. In-river measurements were taken from redds in the upper Yakima River between Easton Dam and the Easton acclimation site. Spawning channel redd measurements were taken in the CESRF experimental spawning channel. Hatchery and wild redds have been pooled. Trait definitions are given in Table 1 and means in Appendix 2.

| Measurement | Source | *SSQ* | *df* | *MSQ* | *F*-ratio | *p*-value |
|---|---|---|---|---|---|---|
| Bowl fwd. depth | Site | 0.415 | 1 | 0.415 | 43.66 | <0.001 |
| | Error | 0.456 | 48 | 0.010 | | |
| Bowl fwd velocity | Site | 4.621 | 1 | 4.621 | 136.40 | <0.001 |
| | Error | 1.626 | 48 | 0.033 | | |
| Bowl max depth | Site | 0.532 | 1 | 0.532 | 70.64 | <0.001 |
| | Error | 0.362 | 48 | 0.008 | | |
| Tail fwd depth | Site | 0.618 | 1 | 0.618 | 87.51 | <0.001 |
| | Error | 0.339 | 48 | 0.007 | | |
| Tail fwd velocity | Site | 3.395 | 1 | 3.395 | 162.09 | <0.001 |
| | Error | 1.005 | 48 | 0.021 | | |
| Left depth | Site | 0.529 | 1 | 0.529 | 39.14 | <0.001 |
| | Error | 0.649 | 48 | 0.014 | | |
| Left velocity | Site | 7.603 | 1 | 7.603 | 357.29 | <0.001 |
| | Error | 1.021 | 48 | 0.021 | | |
| Right depth | Site | 0.410 | 1 | 0.410 | 42.15 | <0.001 |
| | Error | 0.467 | 48 | 0.010 | | |
| Right velocity | Site | 4.543 | 1 | 4.543 | 152.66 | <0.001 |
| | Error | 1.428 | 48 | 0.030 | | |
| Tail back depth | Site | 0.109 | 1 | 0.109 | 15.50 | <0.001 |
| | Error | 0.329 | 47 | 0.007 | | |
| Tail back velocity | Site | 6.460 | 1 | 60460 | 246.32 | <0.001 |
| | Error | 1.233 | 47 | 0.026 | | |
| Max redd length | Site | 46.642 | 1 | 46.642 | 26.23 | <0.001 |
| | Error | 85.360 | 48 | 1.778 | | |
| Max width | Site | 29.664 | 1 | 29.664 | 70.37 | <0.001 |
| | Error | 20.236 | 48 | 0.422 | | |
| Bowl length | Site | 0.005 | 1 | 0.005 | 0.020 | 0.888 |
| | Error | 12.853 | 48 | 0.268 | | |
| Tail length | Site | 41.599 | 1 | 41.599 | 34.58 | <0.001 |
| | Error | 57.751 | 48 | 1.203 | | |
| Bowl depth | Site | 0.014 | 1 | 0.014 | 4.57 | 0.038 |
| | Error | 0.145 | 48 | 0.003 | | |